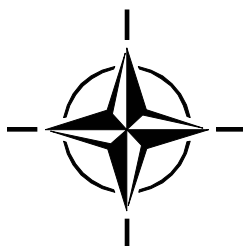**RTO TECHNICAL REPORT**   **TR-MSG-006**

M&S Support to Assessment of Extended Air Defence C2 Interoperability

(Soutien M&S de l'évaluation de l'interopérabilité entre le C2 et la défense aérienne élargie)

Work performed by the RTO NATO Modelling and Simulation
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M&S Support to Assessment of Extended Air Defence C2 Interoperability

(Soutien M&S de l'évaluation de l'interopérabilité entre le C2 et la défense aérienne élargie)

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The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote co-operative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective co-ordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also co-ordinates RTO's co-operation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of co-operation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT   Applied Vehicle Technology Panel
- HFM   Human Factors and Medicine Panel
- IST   Information Systems Technology Panel
- NMSG   NATO Modelling and Simulation Group
- SAS   Studies, Analysis and Simulation Panel
- SCI   Systems Concepts and Integration Panel
- SET   Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier co-operation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

M&S Support to Assessment of Extended Air Defence C2 Interoperability
(RTO-TR-MSG-006)

Executive Summary

Extended Air Defence (EAD) began with an appreciation of the risks posed to the Alliance by the proliferation of NBC weapons and their delivery means, and recognition that NATO's new Strategic Concept necessitated the protection of (deployed) NATO forces, territory and population against ballistic missiles. Within NATO, some countries already have ATBM (Anti-TBM) capabilities, others are in the process of acquiring these capabilities. One of the most important issues that may be addressed will be **interoperability** between all TBM defence architecture elements within NATO: especially the **Command and Control elements**; tactical and procedural co-ordination between combined and joint EAD forces; and deployment and contribution of future elements (for instance airborne laser). NATO and the nations can do something to improve Command & Control and "**turn individual weapon systems (point solutions) into a defense system**". The only way of knowing what Nations should do is to explore through simulation (and progressively work to a situation where the simulated elements are replaced by real ones). This simulation environment could also provide a training framework.

The NATO RTO Modelling and Simulation Group (NMSG) recognised the important role that interoperable simulations could play in the EAD field and set up the MSG006/TG006 Task Group to investigate this area. This report is the result of the study performed by the TG exploratory group. The report describes the issues relating to EAD and C2 (e.g. C2 interoperability within NATO), the current use of Modelling and Simulation (M&S) to support the EAD field (e.g. training, research and analysis) and it identifies opportunities for improved support through M&S.

The TG believes that with respect to EAD, the performance of the weapon systems is as given. Nations and NATO can get the best value for money through the Command and Control and co-ordinate the weapons, provide warnings for passive defense, cue sensors, etc.

The findings of the study include the fact that although HLA is the accepted standard for M&S interoperability, many existing models and simulations can not effectively interoperate due to lack of compliancy either to HLA or to a standardised datamodel (i.e. FOM). The study group identified the need for standard FOMs that cover tactical datalinks (TDLs) and recommends the TDL FOMs currently under development within the Simulation Interoperability Standards Organisation (SISO).

One of the conclusions coming out of NATO's Active Layered Theatre Ballistic Missile Defence Feasibility Study (ALTBMD FS) is the need for a testbed to reduce the schedule risks associated with the integration of a variety of weapon, sensors, and BMC3 systems. The TG proposes to set up a programme to demonstrate the possibilities of M&S to C2 interoperability in the EAD area. This programme will be a follow-on to the work of the current MSG006/TG006 and it will demonstrate solutions to the problems identified (e.g. a reference FOM). This activity will primarily take place in 2004/2006 and will depend on the selection of suitable national programmes that can serve as a framework. By establishing a distributed testbed capability, integration and interoperability issues can be identified and resolved well in advance of system fielding. Activities and results of the MSG006 follow-on project should be co-ordinated and harmonised with the ALTBMD programme of the CNAD/Missile Defence project Group. Results of this

study could also be applied to any future European BMD project with an emphasis on its linkage with the US BMD. The MSG006/TG006 will prepare a SOW/TOR document to propose the follow-on project.

MSG006/TG006 was co-chaired by Mr. Stephen Goodenough (QinetiQ, UK) and Mr. Wim Huiskamp (TNO-FEL, The Netherlands). Permanent representatives from France, The Netherlands, Turkey, the United Kingdom, the United States and NC3A participated in the TG and NIAG was represented by a French delegate.

Soutien M&S de l'évaluation de l'interopérabilité entre le C2 et la défense aérienne élargie

(RTO-TR-MSG-006)

Synthèse

La question de la défense aérienne élargie (EAD) s'est fait jour suite à la prise de conscience des risques posés à l'Alliance par la prolifération des armes nucléaires, biologiques et chimiques (NBC) et de leurs vecteurs, ainsi que par la constatation que le nouveau concept stratégique de l'OTAN nécessitait la protection des forces (déployées), des territoires et des populations de l'Alliance contre les missiles balistiques. Au sein de l'OTAN, certains pays disposent déjà de moyens ATBM (anti-missile balistique tactique). D'autres sont en train de les acquérir. L'une des questions les plus importantes à examiner à l'avenir sera celle de **l'interopérabilité** entre l'ensemble des éléments d'architecture de défense contre les TBM au sein de l'OTAN et en particulier les éléments de **commandement et de contrôle**, la coordination des tactiques et procédures entre les forces EAD interarmées multinationales, ainsi que le déploiement et la contribution d'éléments futurs (par exemple le laser aéroporté). Certes, l'OTAN et ses pays membres sont en mesure d'améliorer le commandement et le contrôle et de « **transformer des systèmes d'armes individuels (solutions ponctuelles) en un système de défens**e ». Mais le seul moyen de déterminer la voie à suivre est d'examiner les différentes possibilités d'amélioration à l'aide de la simulation (et de remplacer progressivement ainsi les éléments simulés par des éléments réels). Cet environnement de simulation pourrait également fournir le cadre de futures activités d'entraînement.

Ce Groupe OTAN/RTO de modélisation et de simulation (NMSG) a reconnu le rôle important que les simulations interopérables seraient susceptibles de jouer dans le domaine de l'EAD et a créé le Groupe de travail MSG006/TG006 pour étudier cette question. Le présent rapport est le résultat de l'étude réalisée par le groupe exploratoire TG. Le rapport traite d'un certain nombre de questions relatives à l'EAD et au C2 (par exemple l'interopérabilité C2 au sein de l'OTAN), la mise en œuvre actuelle de la M&S au profit de l'EAD (par exemple l'entraînement, la recherche et les analyses), ainsi que les perspectives d'amélioration de ce soutien par le biais de la M&S.

En ce qui concerne l'EAD, les performances des systèmes d'armes sont celles indiquées. Pour l'OTAN et ses pays membres, le commandement et le contrôle représentent le meilleur moyen d'optimiser leurs ressources, de coordonner l'exploitation de leurs systèmes d'armes, de fournir des alertes pour la défense passive, d'aligner les capteurs, etc.

Parmi les conclusions de l'étude, il a été précisé que, bien que HLA soit la norme admise pour l'interopérabilité M&S, bon nombre de modèles et de simulations ne sont pas interopérables en raison de leur non-conformité soit à HLA, soit à l'un des modèles de données normalisés (c'est-à-dire FOM). Le groupe a recommandé l'établissement de FOM normalisés couvrant les liaisons de données tactiques (TDL), avec comme modèle les FOM de TDL actuellement en cours de développement par l'Organisation de normalisation de l'interopérabilité de la simulation (SISO).

L'étude de faisabilité OTAN sur la défense échelonnée contre les missiles balistiques de théâtre (ALTBMD FS) a conclu qu'il fallait prévoir un banc d'essai afin de réduire les risques de programmation associés à l'intégration d'une multiplicité de systèmes d'armes, de capteurs et de systèmes BMC3. Le groupe a l'intention d'élaborer un programme permettant de démontrer les possibilités offertes par la

M&S pour l'amélioration de l'interopérabilité du C2 dans le domaine de l'EAD. Ce programme, qui est complémentaire des travaux de l'actuel groupe MSG006/TG006, fournira des solutions aux problèmes identifiés (par exemple un FOM de référence). Cette activité se déroulera entre 2004 et 2006 en principe, en fonction de l'adéquation des programmes nationaux proposés comme cadre. L'établissement d'un banc d'essai réparti permettra d'identifier et de résoudre d'éventuels problèmes d'intégration et d'interopérabilité bien avant la mise en service des systèmes. Les activités et les résultats du projet complémentaire MSG006 devraient être coordonnés et harmonisés avec le programme ALTBMD du Groupe CDNA sur le projet de défense contre les missiles. Etant donné leurs liens avec le BMD US, les résultats de cette étude pourraient également être incorporés à toute autre étude BMD européenne réalisée à l'avenir. Le groupe MSG006/TG006 élaborera un document SOW/TOR en vue de la proposition du projet complémentaire.

Le groupe MSG006/TG006 a été coprésidé par M. Stephen Goodenough (QinetiQ, UK) et par M. Wim Huiskamp (TNO-FEL, Pays-Bas). Des représentants permanents de la France, des Pays-Bas, de la Turquie, du Royaume-Uni, des Etats-Unis et de la NC3A ont participé aux travaux du TG, et le NIAG a été représenté par un délégué français.

Table of Contents

Chapter 5 – Modelling and Simulation Issues and Responses   5-1

Chapter 6 – M&S Infrastructure to Validate EAD C2 Interoperability   6-1

Chapter 7 – Conclusions and Recommendations   7-1

References   R-1

Appendix A – Report Contributors   A-1

Glossary

AAP	Area Air Picture
AAWC	Anti Air Warfare Commander
ABL	Airborne Laser
ACC	Air Control Centre
ACCS	Air Command and Control System
ACO	Air-Space Control Order
ActD	Active Defence
AD	Air Defence
ADF	Air Defence Frigate
AEW	Airborne Early Warning
ALTBMD	Active Layered Theatre Ballistic Missile Defence
AOCC	Air Operation Co-ordination Centre
AOR	Area of Responsibility
ARCENT	Army Forces Central Command
ARM	Anti Radiation Missile
ARS	ACC, RPC, and SFP Collocated Site
ASM	Air to Surface Missile
ATBM	Anti Tactical Ballistic Missile
ATC	Air Traffic Control
ATM	Air Tasking Message
ATO	Air Tasking Order
AWCIES	ACCS Wide Common Information Exchange Standards
BM	Ballistic Missile
BMC3I	Battle Management, Command, Control, Communication and Intelligence
C2	Command and Control
CAMDEN	Co-operative Air and Missile Defence Exercise Network
CAOC	Combined Air Operations Centre
CAP	Combat Air Patrol
CAPS	Commander Analysis Planning System
CARS	CAOC, ACC, RPC, and SFP Collocated Site
CASP	Combined Air-Sea Procedure
CAX	Computer Assisted eXercise
CC	Cannon Cloud (exercise)
CCF	Conventional Counter Force
CF	Counter Force
CJTF	Combined Joint Task Force
CM	Cruise Missile
CMO	Coverage Mission Order
CNAD	Committee of National Armaments Directors
CNI	Communication, Navigation and Identification
COEA	Cost and Operational Effectiveness Analyses
CONOPS	CONcept of OPerationS
COP	Common Operational Picture

CPX	Command Post Exercise
CSDTS	Common Shipboard Data Terminal Set
DAC	Deployable ACCS Component
DARS	Deployable ARS
DCAOC	Deployable CAOC
DiMuNDS	Distributed Multi-National Defence Simulation
DIS	Distributed Interactive Simulation
DIS-EBV	Distributed Interactive Simulation Enumeration Bit Values
DOD	Department of Defense
DOF	Degrees of Freedom
EAD	Extended Air Defence
EADSIM	Extended Air Defence Simulation
EADTB	Extended Air Defence Testbed
ECM	Electronic Counter Measures
ESAMS	Enhanced Surface-to-Air Missile Simulation
ET	Exploratory Team
EW	Early Warning
FCM	Federation Conceptual Model
FEDEP	Federation Development Process (HLA term)
FOM	Federation Object Model (HLA term)
GAF	German Air Force
GBAD	Ground Based Air Defence
GBR	Ground Based Radar
HALE	High Altitude Long Endurance (UAV)
HAPPIE/RIOT	Hazard Area Prediction by Perturbations In Ensembles / Risk of Intercept Of TBMs
HCAOC	Hybrid CAOC
HIL	Human in the Loop
HLA	High Level Architecture
ICC	Interim CAOC Capability
IEEE	Institute of Electrical and Electronics Engineers
ISR	Intelligence, Surveillance and Reconnaissance
JFACC	Joint Forces Air Component Commander
JNIC	Joint National Integration Centre (US)
JPOW	Joint Project Optic Windmill
JPTL	Joint Prioritised Target List
J-ROADS	Joint Research On Air Defence Simulation
JSRC	Joint Sub-Regional Command
JTDLMP	Joint Tactical Data Link Management Plan
JTIDS	Joint Tactical Information Distribution System
JTLS	Joint Theatre Level Simulation
JWID	Joint Warrior Interoperability Demonstration

LAN	Local Area Network
LAP	Local Air Pictures
LBL	Land Based Lower
LBU	Land Based Upper
LCC	Land Component Commander
LOC	Level of Operational Capability
LSID	Link16 SAMC2 Interoperability Demonstrator
M&S	Modelling and Simulation
MAOP	Master Air Operation Priorities
MCC	Maritime Component Commander
MDA	Missile Defence Agency (US)
MDWAR	Missile Defence Wargame and Analysis Resource
MEZ	Missile Engagement Zone
MIDS	Multifunction Information Distribution System
MJLC	Multinational Joint Logistic Centre
MNAF	Multi-National Air Forces
MND	Multi-National Defence
MNLF	Multi-National Land Forces
MNMTF	Multi-National Maritime Task Forces
MOE	Measures of Effectiveness
MOP	Measures of Performance
MOR	Military Operational Requirement
MOSAIC	Modelling System for Advanced Investigation of Countermeasures
MSG	Modelling and Simulation Study Group
MSMP	Modelling and Simulation Master Plan
NADC	NATO Air Defence Committee
NATO	North Atlantic Treaty Organisation
NBC	Nuclear, Biological or Chemical
NIETI	NATO Interoperability Environment Testing Infrastructure
NIETWG	NATO Interoperability Environment Testing Working Group
NILE	NATO Improved Link Eleven
NRT	Non Real-Time
OCA	Offensive Counter Air
OMT	Object Model Template
OPCOM	Operational Command
OPCON	Operational Control
PAC	PATRIOT Advanced Capability
PATRIOT	Phased Array Tracking Radar to Intercept On Target
PD	Passive Defence
PDU	Protocol Data Unit
PGM	Precision Guided Munitions
Pk	Probability of Kill
PPLI	Precise Participation Location & Identification
R2	Reporting Responsibility

RAP	Recognised Air Picture
RC	Response Cell
RC	Regional Command
RCS	Radar Cross Section
RF	Radio Frequency
RNLAF	Royal Netherlands Air Force
ROE	Rule Of Engagement
RPC	RAP Production Centre
RPR FOM	Real-time Platform Repository
RRF	Rapid Reaction Force
RSR	Radar Service Requests
RT	Real-Time
RTB	Research & Technology Board
RTI	Run-Time Infrastructure (HLA term)
SAM	Surface to Air Missile
SAMOC	Surface to Air Missile Operation Centre
SAMP/T	Sol-Air Moyenne Portée Terrestre (Surface-to-Air Missile Portable/Land)
SBL	Sea Based Lower
SBU	Sea Based Upper
SC	Strategic Command
SEAS	System Effectiveness Analysis Simulation
SEW	Shared Early Warning
SFP	Sensor Fusion Post
SIMPLE	Standard Interface for Multiple Platform Link Evaluation
SISO	Simulation Interoperability Standards Organisation
SOF	Special Operation Force
SOM	Simulation Object Model
SQOC	Squadron Operation Centre
SRC	Sub Regional Command
STANAG	STANdardisation AGreement
TADIL	Tactical Digital Information Link
TACOM	Tactical Command
TACON	Tactical Control
TAMD	Theatre Air and Missile Defence
TBM	Tactical Ballistic Missile
TBMD	Tactical Ballistic Missile Defence
TDL	Tactical Data Link
TDLITS	Tactical Data Link Interoperability Testing Syndicate
TDMA	Time Division Multiple Access
TDS	Tactical Data Systems
TEL	Transporter-Erector-Launcher
TG	Task Group
TM	Tactical Missile
TMD	Theatre Missile Defence
TTP	Tactics, Techniques and Procedures

UAV	Unmanned Aerial Vehicle
USEUCOM	US European Command
WAN	Wide Area Network
WMD	Weapons of Mass Destruction
WOC	Wing Operation Centre
XML	eXtensible Mark-up Language

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Chapter 1 – INTRODUCTION:
BACKGROUND AND STUDY OBJECTIVES

1.1 BACKGROUND

Due to the evolving threat of Tactical Ballistic Missiles (TBMs), and in particular TBMs using biological and chemical agents, an effective defence against this threat is of utmost importance. Within NATO some countries already have ATBM (Anti-TBM) capabilities. Others are in the process of acquiring these capabilities. Furthermore, under the umbrella of NATO, several research and acquisition programs are underway. A program in which all 19 NATO nations participate currently is the NATO Feasibility Study for an active layered Theatre Ballistic Missile Defence (Ref [3] and Ref [5] [1]). This study addresses the feasibility of an effective integrated architecture, consisting of early warning sensors, satellites, lower/upper tier weapons systems and Battle Management, Command, Control, Communications, and Intelligence (BMC3I) elements.

The BiSC CONOPS for EAD (Ref [1]) identifies the risks associated with TBMs, cruise missiles and UAVs (possibly with WMD) and proposes a CONOPS for 2010 and beyond. Optimal execution of the CONOPS requires that all elements of the future TMD architecture are integrated to achieve maximum attrition of enemy assets, economical expenditure of own assets and minimising the risk of fratricide. This is achieved through appropriate integration of all elements of the future EAD architecture. Problems are to detect, acquire, identify and track TBMs (ranging from slow, low flying CMs and UAVs to high velocity, high flying missiles), while discriminating between warheads, decoys and debris. TBMs are to be destroyed at the greatest distance from friendly assets and population. Clearly, interoperability and full systems integration is central to success.

Simulation plays an important role in analysing future TBMD architectures. One of the most important issues that may be addressed will be interoperability between all TBMD architecture elements: especially the Command and Control elements; tactical and procedural co-ordination between combined and joint EAD forces; and deployment and contribution of future elements (for instance airborne laser).

The NATO RTB Modelling and Simulation Group (NMSG) recognised the important role that interoperable simulations could play in the TBMD field and set up a Task Group to investigate this area. The Task Group would conduct a large, multi-year, development and integration effort that will lead to a NATO-wide distributed simulation infrastructure for assessing Extended Air Defence (EAD) Command and Control (C2) interoperability. The NATO MSG006 Task Group on "M&S Support to Assessment of Extended Air Defence C2 Interoperability" started its activities in June 2001. Members of the Task Group are from the United Kingdom, France, the United States, Turkey and The Netherlands. NC3A representatives provided additional support to the group.

This document is the first report out of the MSG006 "Exploratory" Team, it provides an overview of the research field and presents proposals for the way ahead.

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[1] At the Prague Summit, the Heads of State and Government agreed "to examine options for protecting Alliance territory, forces and population centres against the full range of missile threats in an effective and efficient way through an appropriate mix of political and defence efforts, along with deterrence; in particular they agreed to initiate a new NATO missile defence feasibility study".

1.2   INTEROPERABILITY DEFINITION

NATO defines interoperability as:

> "The ability of systems, units or forces to provide services to and accept services from other systems, units or forces and to use the services so exchanged to enable them to operate effectively together."[2]

NATO has defined the following Degrees of Interoperability (Ref [4]):

Degree 0: Not connected.

Degree 1: Unstructured Data Exchange (Network, document exchange, Messages) – involves the exchange of human-interpretable unstructured data such as the free text found in operational estimates, analysis and papers.

Degree 2: Structured Data Exchange (Network Management, Data Object Exchange/Replication, Web) – involves the exchange of human-interpretable structured data intended for manual and/or automated handling, but requires manual compilation, receipt and/or message dispatch.

Degree 3: Seamless Sharing/Exchange of Data (Common data exchange, system and security management) – involves the automated sharing of data between systems based on a common exchange model.

Degree 4: Seamless Sharing/Exchange of Information (Common information, Knowledge bases, Distributed Applications) – an extension to Degree 3 to achieve the universal interpretation of information through data processing based on co-operating applications.
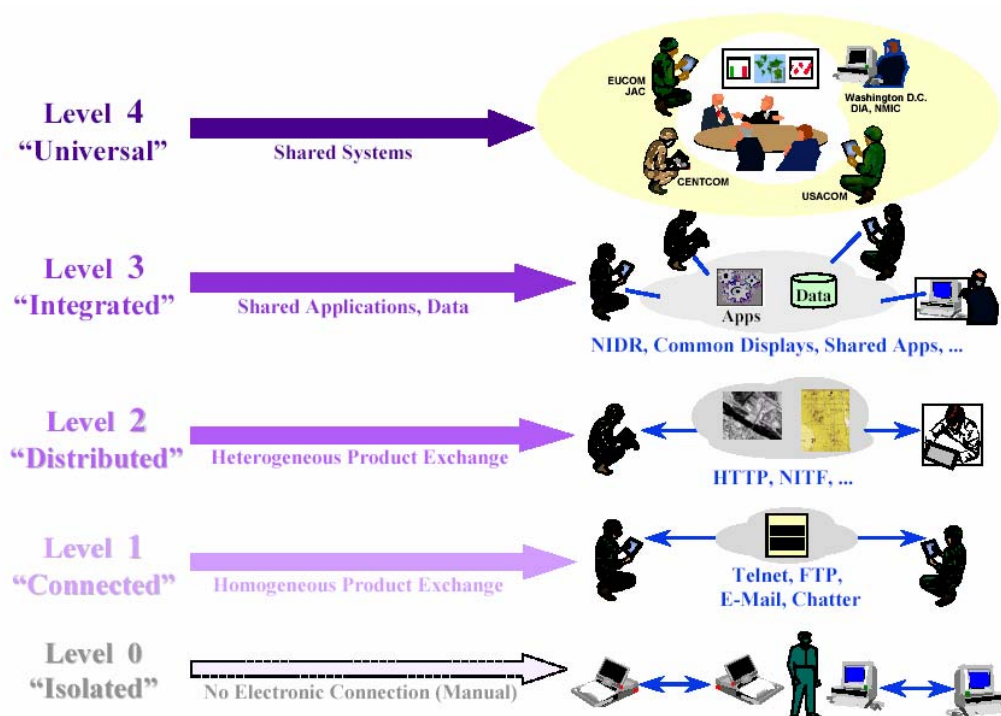
Figure 1.2-1: Levels of Data Exchange (note "levels" used for "degrees" in this figure).

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[2] NATO definition in AAP-6.

The target should be to achieve Degree 4 for C2 interoperability.

1.3   OBJECTIVES

The prime purpose of this study group is to consider how simulations and the mapping between real C2 systems and simulations can support improvements to the interoperability between the real C2 systems themselves.

We need to distinguish between:

*   Interoperability between real world C2 systems. (This is the ultimate goal for NATO)

*   Interoperability between C2 systems and simulations. (Necessary for a testbed)

*   Interoperability between simulations. (This is a necessary tool)

This is illustrated in the following figure.
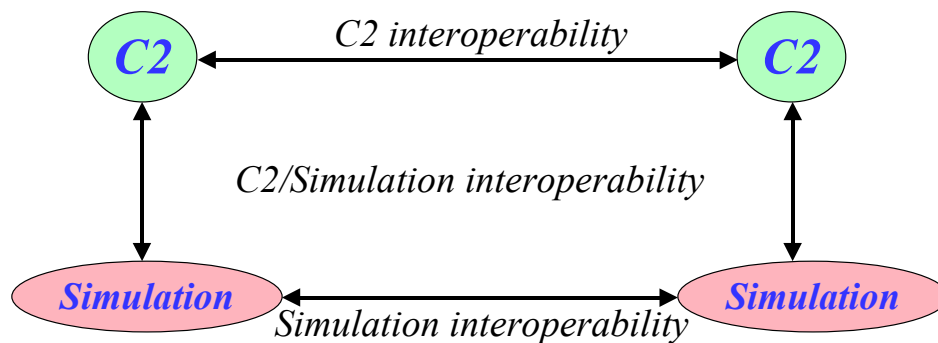
Figure 1.3-1: Relationship between Real and Simulation Domains.

A common distributed simulation architecture for EAD is desired. This would have the following advantages:

*   allow the use of the simulation architecture within EAD exercises (and/or other NATO programmes) to simulate elements that cannot contribute as real elements (not developed yet, too costly to use, security restrictions, safety restrictions);

*   allow NATO to re-use existing assets (simulations and databases);

*   provide a higher degree of commonality through the use of common object models and terminology;

*   allow the inclusion of real C2 elements for test and validation.

The MSG006 objective is to identify the most appropriate and cost-effective implementation of a distributed simulation architecture for assessing current and future EAD C2 interoperability capabilities. The aim will be:

*   to develop a distributed simulation architecture across NATO member nations that enables analysis of the issues raised above (interoperability, tactical/procedural co-ordination, deployment of future elements); and

*   to assess the feasibility of linking this architecture with already existing simulation elements across all NATO nations (e.g. EADSIM in NL, EADTB at NC3A, Joint National Integration Centre in US, and EAD exercises such as Joint Project Optic Windmill (JPOW).

This project will be a large, multi-year, development and integration effort that will rely heavily on available national and NATO simulation resources. Initially, therefore, an Exploratory Team (ET) was established to:

- catalogue existing TBMD simulation assets in member nations, including features and applications;

- develop a philosophy for a standard simulation infrastructure;

- identify the steps to migrate from existing 'stand-alone' simulation assets towards a standard architecture; and

- develop terms of reference material, etc.

This document is the result of the Exploratory study.

1.4   DOCUMENT STRUCTURE

Chapter two discusses the EAD domain and the related C2 interoperability problems. Chapter three outlines the EAD C2 requirements of federating simulations for the purpose of addressing NATO interoperability issues.

Chapter four describes the current state of Modelling & Simulation, notably the role of the High Level Architecture (HLA). Chapter four also discusses the current use of M&S for EAD related research and it gives an overview of representative applications and tools (see Appendices B, C, D and E for details).

Chapter five discusses the way in which M&S may support the issues related to C2 EAD interoperability. Chapter six proposes the M&S infrastructure that is to be developed in the follow-on project of MSG006/TG006. Finally, Chapter seven provides conclusions and recommendations.

Chapter 2 – DESCRIPTION OF THE EAD DOMAIN AND THE RELATED C2 INTEROPERABILITY PROBLEMS

2.1   INTRODUCTION TO EAD[1]

Extended Air Defence began with an appreciation of the risks posed to the Alliance by the proliferation of NBC weapons and their delivery means, and recognition that NATO's new Strategic Concept necessitated the protection of NATO forces, territory and population against ballistic missiles. A concept for extended air defence that integrates ballistic and cruise missile (CM) defence into existing air defence missions has since been adopted by the Alliance and a military operational requirement for TBMD (Ref [8]) has been produced by NATO's military authorities. This concept distinguishes the three "EAD-pillars" active defence (ActD), passive defence (PD) and conventional counterforce/attack operations (CCF) supported by a "foundation" of Battle Management/Command & Control, Communications, Intelligence (BM/C3I) within the context of political measures such as treaties and deterrence.
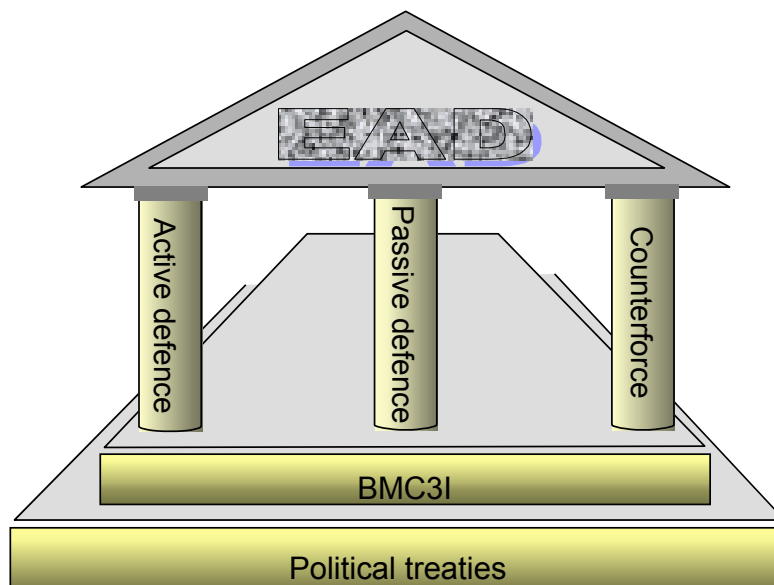
Figure 2.1-1: Pillars of Extended Air Defence.

The definition of Extended Air Defence (EAD), in combination with Theatre Air and Missile Defence (TAMD), is given in reference [2]:

> "The existing air defence and its extension to counter conventionally the entire air threat which is posed by tactical missiles, including cruise missiles, or any air breathing enemy vehicle which threatens friendly assets."

The three main pillars can have different requirements for the BM/C3I and interoperability support. Therefore, the Task Group recognises the need for addressing all of the pillars when dealing with BM/C3I and interoperability issues.

The Task Group shall distinguish between the three main pillars and the BM/C3I foundation, but will report their results in an integrated manner. For example, attack operations require a wide range of sensors and rapid dissemination of both general intelligence information and launch information, to allow for

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[1] The text of this paragraph is mainly drawn from Ref [7].

planning of attack operations and immediate tasking. Active defence operations require dissemination of cueing information from early warning sensors to weapon systems. Depending on the C2 and communications architecture, this may require data fusion techniques to improve the track quality with a low-latency, high-volume distribution of sensor data.

2.1.1   Active Defence

Active defence measures are actions taken to destroy or mitigate the effectiveness of an enemy attack by intercepting enemy threats in flight. Active defence consists of defence in depth against all classes of manned aircraft and tactical missiles (e.g. Cruise Missile (CM), Tactical Ballistic Missile (TBM), Anti-Radiation Missile (ARM), Air-to-Surface Missile within the theatre), including Weapons of Mass Destruction (WMD). Active defence measures can be categorised as follows:

1) Lower layer defence systems, including ground/sea-based and air terminal systems, with intercepts typically in the region up to ~35 km altitude;

2) Upper layer defence systems, with intercepts typically above ~35 km altitude; and

3) Boost phase intercept systems.

The U.S. Missile Defence Agency (MDA) distinguishes 3 phases in ballistic missile defence: (1) Boost phase defence, (2) Midcourse defence, (3) Terminal Defence (upper layer and lower layer). The defence systems are ground-, sea-, air- or space-based.

2.1.2   Passive Defence

Passive defence measures are actions taken to minimise the effectiveness of enemy actions on friendly assets and include techniques utilised to:

1) degrade enemy targeting capability (e.g. camouflage, dispersal);

2) reduce the vulnerability of Alliance assets to attack (e.g. hardening, mobility);

3) facilitate reconstitution of capability after an attack (e.g. redundancy, rapid repair capability, decontamination);

4) exercise an extension of Civil Defence warning; and

5) monitor and evaluate PD-NBC effects through available channels.

2.1.3   Conventional Counter Force/Attack Operations

A principal objective of CCF is to prevent the launch of tactical (ballistic) missiles by neutralising essential elements of the opponents' TM attack capability. The elimination at the source has the potential advantage of engaging WMD within the opponent's territory.

Key aspects of successful CCF include:

1) an integrated "sensor-to-shooter" capability, including appropriate sensor coverage, that supports stressing timelines;

2) accurate intelligence information to properly assess opponents' TM threat processes and vulnerabilities;

3) accurate and timely warning and targeting information (e.g. Launch Point Prediction);

4) an agreed political framework covering specific criteria for authorising the use of CCF capabilities; and

5) different methods and weapons systems to attack CF targets.

Representations of CCF Operations should include the prioritisation among targets, direct surveillance changes and direct strikes on targets. The strikes on targets can be surface-to-surface engagements or air-to-surface engagements.

2.1.4   Battle Management/Command and Control, Communications and Intelligence

BM/C3I comprises the capabilities, processes, procedures and information for co-ordinating and synchronising both offensive and defensive measures during peace, crisis and war. A joint, combined, integrated BM/C3I system is the 'central core' that supports passive as well as active defence and CCF. The BM/C3I system should provide:

1) detection, identification (ID), tracking and cueing;

2) interoperability of links; timely transfer of data;

3) interconnectivity between systems;

4) the required protocol for pre-authorisation and weapon assignments; and

5) the capability for rapid deployability and operation.

The BMC3I element is responsible for the coordination and integration of weapon and sensor systems, possibly developed by different nations and most likely distributed widely over land, sea, air and even space. BMC3I is critical to the successful execution of the ballistic missile defence mission. Without it, the various weapon and sensor systems would act independently and ineffectively, wasting resources, and placing forces unduly at risk. NATO recognises this importance and is actively identifying missile defence related requirements for the NATO Air Command and Control System (ACCS). The NATO ACCS LOC1 capability is currently scheduled for initial operational capability in 2006.

In the picture below the NATO military structure for EAD along with some of the related ACCS entities are displayed, with a distinction made between operational and tactical C2 levels. The Strategic Command (SC) is at the level of Operational Command, and the Regional and Sub Regional Command (RC, SRC) are at the level of Operational Control. The CAOC (Combined Air Operation Centre) is at the Tactical Command, and at the Tactical Control level the ACC (Air Control Centre), AAWC (Anti Air Warfare Commander), AOCC (Air Operations Co-ordination Centre), RPC (RAP Production Centre), SFP (Sensor Fusion Post), SAMOC (SAM Operation Centre), WOC (Wing Operation Centre) and SQOC (Squadron Operation Centre) might operate.

The Air Defence Frigate (ADF) is included in two different roles. An ADF in an Anti Air Warfare Commander role is included as a 'sea-based Air Control Centre' (ACC). An ADF in a normal Air Defence role is included as a 'sea-based SAMOC'.
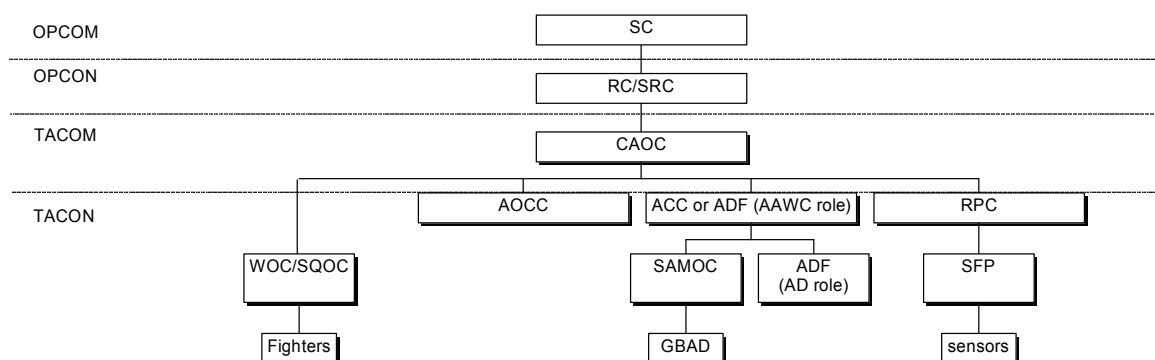
Figure 2.1-2: ACCS Entities under the NATO Military Command Structure.

Because BMC3I is the primary EAD functional area addressing interoperability, and because ACCS will be NATO's BMC3I system for air defence, the following section will describe the ACCS entities in more detail.

ACCS Entities

The NATO command and force structures, together with geographical and span of control considerations, lead to a natural division of the ACCS into a number of design areas. Each design area encompasses in-place air forces and may expect, in a time of crisis, the possibility of receiving reinforcement or augmentation forces, including ACCS elements. Thus, each design area requires sufficient ACCS entities, embracing the full peace, crisis and war capability, to manage the forces in-place and the early elements of reinforcement. In that context, the minimum ACCS will consist of static and non-static elements embedded in an in-place system. A proportion of the non-static elements will be committed to a Deployable ACCS Component (DAC) enabling reinforcement and augmentation of any design area.

Each design area will incorporate at least one Combined Air Operations Centre (CAOC) for tasking of assigned air assets, adequate air mission control entities (Air Control Centres (ACCs)) to manage both the Main Defence Forces within the design area and a proportion of the Rapid Reaction Force (Air) and adequate surveillance entities, Recognised Air Picture Production Centres (RPC) and Sensor Fusion Posts (SFP) to allow the receipt of data from various sensor sources, both from within and outside the ACCS programme, to provide the basis for and the maintenance of a RAP. These four types of entity, CAOC, ACC, RPC and SFP constitute the ''core'' ACCS entities.

WOC, SQOC, AOCC and SAMOC will provide the essential information base to the ''core'' entities and will enable the Alliance weapons systems to react efficiently. The AOCC will ensure effective integration of both land and maritime forces into the air campaign.
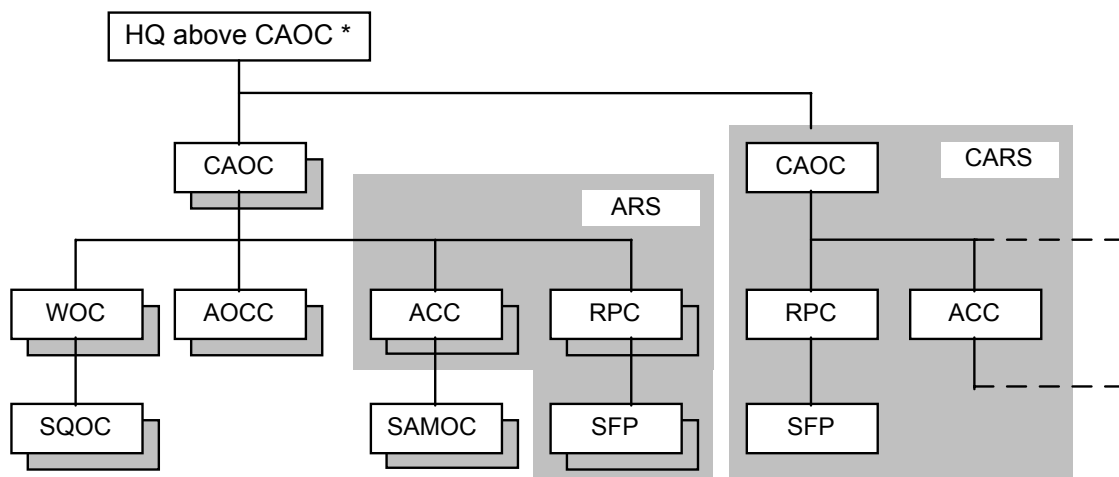
Figure 2.1-3: ACCS Site Hierarchy (ACCS LOC1 Sites are in shaded boxes).

Combined Air Operations Centre (CAOC)

The CAOC plans and conducts tasking of air operations and C2 resources configuration with assigned, allotted and allocated resources within a designated AOR (Area Of Responsibility). The tasking is based on higher level directives and lower level reporting. Execution of tasking is supervised, monitored and results are analysed. The CAOC co-ordinates with land, maritime and national forces as well as with other NATO and national agencies.

Air Control Centre (ACC)

The ACC is the real-time battle management entity in the ACCS that performs air mission control for all types of manned air missions and SAM weapons within a designated geographical area. Furthermore, it provides SAM weapon preparation and ATC (Air Traffic Control) services.

RAP Production Centre (RPC)

The RAP Production Centre (RPC) produces and disseminates RAP data within its assigned AOR, and manages its subordinate surveillance assets. An Area Air Picture (AAP) is established by correlating Local Air Pictures (LAPs) from subordinate Sensor Fusion Posts (SFPs) with tracks and surveillance data received from sources external to ACCS. An identification is assigned to each track in the AAP, and the resulting RAP data are filtered, disseminated as appropriate, and co-ordinated with AEW surveillance. The RPC also receives land and maritime surface and sub-surface tracks from external links and disseminates them to ACCS users.

The RPC also manages allocated ACCS surveillance assets i.e. orders and priorities received from the CAOC and in response to requests from RAP users for additional or improved RAP data.

Sensor Fusion Post (SFP)

The SFP develops a LAP through the fusion of data from both active and passive sensors. It also reports on the status and performance of subordinate sensors, controls sensor detection and responds to Anti-Radiation Missile (ARM) threats and Electronic Counter Measures (ECM) activity.

Air Operations Co-ordination Centre (AOCC)

The AOCC performs Air Planning Co-ordination and Air Support Management. The AOCC ensures co-ordination of offensive, defensive and support air operations in support of land and maritime operations.

Wing Operations Centre (WOC)

The WOC performs continuous co-ordination between the wing and the CAOC (also AOCC, if tasking authority is delegated) or ACC and between the wing and the squadrons. Feasibility of tasking will be verified throughout the mission preparation process. The tasking will be adjusted for additional mission relevant information and to the wing's capabilities and capacities. Mission launch schedules are generated and missions are assigned to individual squadrons or to individual aircraft. The WOC monitors and ensures mission result reporting and provides continuous near real-time status information to the CAOC.

Squadron Operations Centre (SQOC)

The SQOC performs continuous co-ordination with the WOC for final mission preparation. The SQOC is responsible for the preparation of assigned missions, their timely execution, and the reporting of mission results to the CAOC.

Surface-to-Air Missile Operations Centre (SAMOC)

The SAMOC performs management and control of SAM weapons systems and provides continuous near real-time SAM status information to the ACC, the CAOC and the AOCC (when providing support to ground forces). A SAMOC is normally deployable, but may be implemented in a static installation. A SAMOC may be required to deconflict between upper-layer defence systems as well as between upper and lower-layer systems.

ACCS LOC1 Sites

ACCS First Level of Operational Capability (LOC1) will be implemented in "site" configurations, each of which will consist of one or more ACCS entities. Some entities may also be implemented in deployable configurations.

CAOC/ACC/RPC/SFP Collocated Site (CARS)

In this site configuration, the CAOC, ACC, RPC, and SFP entities will be collocated in a single facility called CARS. With this implementation, global site resources will be shared by all entities whereas entity specific resources will remain independent and separable.

ACC/RPC/SFP Collocated Site (ARS)

In this site configuration, the ACC, RPC, and SFP entities will be collocated in a single facility called ARS. With this implementation, global site resources will be shared by all entities whereas entity specific resources will remain independent and separable.

Deployable ARS (DARS)

The Deployable ARS (DARS) will be strategically deployable and capable of tactical mobility, but will not operate on the move. The DARS will have the functional capability of an ARS and will be designed to be used to augment or reinforce elements of the in-place (static) ACCS structure and it may be employed in roles separate from the in-place ACCS structure as determined by the North Atlantic Council.

The DARS will be self contained and be capable of operating from unprepared sites. The DARS will be housed in standard shelters, which will constitute its basic building blocks.

Deployable CAOC, Hybrid CAOC (DCAOC, HCAOC)

The Deployable CAOC (DCAOC) will be a transportable, strategically deployable unit. The DCAOC equipment will be the same as for a static CAOC, but it will be contained in transport cases, which will constitute the basic building blocks of the deployable configuration.

The DCAOC is designed to be deployed away from its static location to augment or reinforce elements of the in-place ACCS structure and is also capable of being deployed in roles separate from the in-place ACCS structure as determined by the North Atlantic Council.

A Hybrid CAOC (HCAOC) is a single multinational operated ACCS site, comprising a static and a deployable part. Both parts have full CAOC capability and can operate independently from each other. The term "hybrid" refers to equipment and hardware that can be clearly identified as belonging to the deployable or static part.

2.2 C2 INTEROPERABILITY

NATO ACCS will solve many of the interoperability issues associated with the tactical control of extended air defence forces and missions by the simple fact that it will be one integrated system. However, it will still be required to interface with external systems, and therefore will continue to deal with interoperability issues. The three primary areas involving major interoperability challenges for NATO's EAD architecture are:

1) interoperability between the higher echelon commands (SC, RC, CC) and the execution level (ACCS);

2) interoperability between the execution level (ACCS) and the weapon and sensor systems provided by the nations; and

3) interoperability between NATO command structure and those of other nations operating together in a coalition environment.

The first two areas can be described as vertical interoperability challenges (interoperability between different levels of command), while the last area is a case of horizontal interoperability in that it deals with issues within the same level of command. The following figure (see 2.2-1) shows some of the NATO entities that must deal with vertical and horizontal interoperability challenges:
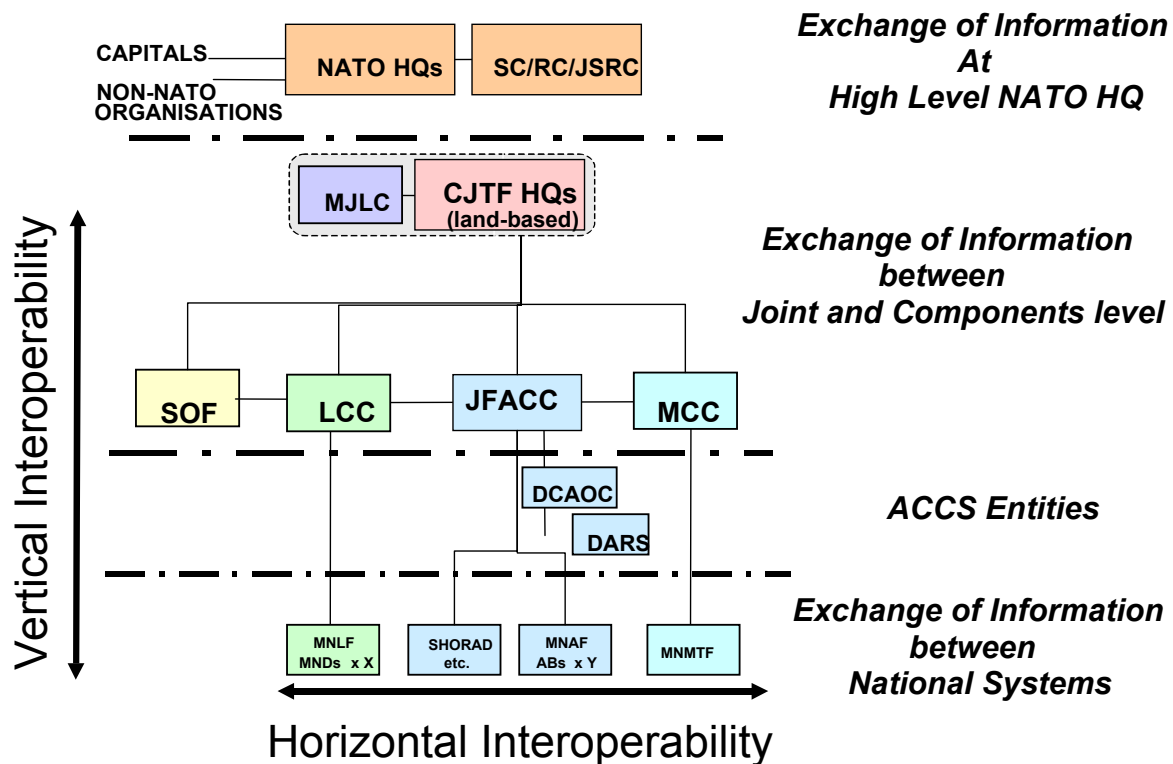
Figure 2.2-1: Interoperability Between and Within Level of Command.

Operational Directive includes:
    Intel, enemy disposition,
    intentions, capabilities
    threat system parameters
    JPTL (Joint Prioritised Target List)
    prioritised defended asset list
    required protection levels
    friendly system capabilities
    geographical data, maps, infrastructure
    meteorological data

Detailed Plan includes:
    Operational Priorities
    Asset apportionment / allocations
    Joint co-ordination
    Active defence / CCF balance
    Surveillance configuration
    Airspace Control Order (ACO)
    Rules Of Engagement (ROE)

Information transmitted down to tactical level:
    Surveillance System Order
    Intelligence, Surveillance and
    Reconnaissance (ISR)
    Airspace Control Order
    SAM, OCA, CAP (Combat Air Patrol)
    planning
    Coverage Mission Order (CMO)
    ROE
    Firing doctrine
    WMD effects / hazard area analysis

Information transmitted up from tactical level:
    Detailed Deployment Plan
    Coverage proposals
    Missile Engagement Zones (MEZ)
    Fighter Engagement Zones (FEZ)

Figure 2.2-2: Representative Data Types for Planning & Tasking at CAOC and Above.

2.2.1   Interoperability with Echelons Above CAOC

For echelons above CAOC, NATO is developing the Bi-Strategic Command Automated Information System (Bi-SC AIS). Interoperability between ACCS and the Bi-SC AIS will primarily involve non-real time planning and tasking directives flowing down to ACCS as well as real time situation and surveillance information flowing up to the Bi-SC AIS so that it can form the Common Operational Picture (COP). Figure 2.2-2 shows representative data elements for echelons above CAOC. Currently, the requirements for the Bi-SC AIS are being defined, and there is a task group being led by NC3A to ensure that interoperability between the Bi-SC AIS and ACCS remains a priority issue.

2.2.2   Interoperability with Weapon and Sensor Systems

For interoperability with the national EAD weapon and sensor systems under NATO's control, ACCS will communicate via the existing tactical data links (TDLs) that these systems already employ. ACCS will use

the AWCIES protocol for communications with entities within ACCS including communications to and from NATO sensors. The data associated with interoperability to weapon and sensor systems is typically real-time in nature and includes missile track data as well as weapon status and engagement control messages.

Tactical data links are mechanisms by which systems can exchange messages in electronic format, and have been used for years to facilitate communication between systems. TDLs are usually made up of a set of predefined messages with a common understanding and are often associated with a specific carrier mechanism (e.g. MIDS radio terminal for Link16).

The common TDLs currently used by NATO and defined in NATO STANAGS are Link-11, Link-16, and Link-22.

Link 11 provides high speed computer-to-computer digital radio communications in the high frequency (HF) and ultra-high frequency (UHF) bands among Tactical Data System (TDS) equipped ships, aircraft and shore sites. Currently the Fleet is using a number of different data terminal sets to provide Link 11 functionality, these include the AN/USQ-74, AN/USQ-83, AN/USQ-120, AN/USQ-125 and other Data Terminal Sets. The new Common Shipboard Data Terminal Set (CSDTS) card set provides all of the capabilities of the older Link-11 data terminal sets including Kineplex, Single Tone, and Satellite transmission capabilities. It also incorporates multi-frequency Link 11 enhancements, allowing the operation of up to four parallel channels among participating units. The CSDTS card set will be included in the Common Data Link Management System.

The Joint Tactical Information Distribution System (JTIDS, also known as Link-16) is the primary NATO standard for tactical datalinks. JTIDS is a communications, navigation and identification system intended to exchange surveillance and C2 information between various C2 platforms and weapons platforms. It provides multiple access, high capacity, jam resistant, digital data and secure voice communication, navigation and identification (CNI) to a variety of platforms. NATO STANAG 5516/MIL STD 6016B describes TADIL-J message formats and the JTIDS network. Link 16 uses a Time Division Multiple Access (TDMA) architecture and the "J" message format standard. The "J" series of message standards are designated as the US Department of Defence's primary tactical data link, according to the Joint Tactical Data Link Management Plan (JTDLMP).

The J-Series messages that are particularly relevant for EAD are show in Table 4.3-1.

Link 22 is the next-generation NATO Tactical Data Link, and is also referred to as the NATO Improved Link Eleven (NILE). Link 22 is a multi-national development program that will produce a "J" series message standard in Time Division Multiple Access architecture over extended ranges.

Web Sites with information on TDLs:

http://cno-n6.hq.navy.mil/N62/ATDLS/ and http://www.stasys.co.uk/tdl/tdl2.htm

2.2.3   Current Issues for EAD C2 Interoperability

As discussed in the earlier section, Command and Control is an evolving complex problem. It involved the combination of non-real-time and real time activities that roughly correspond to the planning and execution phases. The overall Command and Control system comprises many entities linked horizontally and vertically as illustrated in Figure 2.2-1. Whilst some of these entities will have had interoperability issues at the forefront of their designers' minds, the sheer numbers and ages of the entities means that there remain considerable weaknesses in interoperability. A considerable number of standards exist and at the technical level many systems can claim to interoperate. However, at the information level this may not at all be true, because of limitations in the range of messages supported by each individual entity, by misinterpretation of fields within messages or by allowed alternative interpretations.

It is by no means assured that new C2 entities brought into service will interoperate with other legacy entities and there is a clear need for an environment for testing C2 interoperability so that interoperability problems can be recognised and addressed before they become critical during a military operation. It is important to recognise that interoperability is required for both combined and joint operations within and across NATO nations.

The interoperability standards themselves also need care and attention. Once made, a standard change is slow, difficult and expensive. However, many of the existing standards are not well implemented due to alternative interpretations, or indeed the fact that many systems will simply throw away messages, although a future upgrade may make the correct handling of such messages critical.

Previous sections have discussed vertical and horizontal interoperability. Even within a single regime there are different levels of interoperability validation.

We distinguish three level of C2 interoperability shown in the following figure. The operational level is the top level and includes system and technical interoperability. First of all is the technical level: systems need to be connected to each other properly before they can start communicating. Then there is the system level of interoperability: systems need to communicate using a common protocol and message standard. And finally there is the operational level of interoperability: each system needs to fully understand the contents of the other's messages and know how that data relates to its own information.

The validation of operational level interoperability requires exercises with operational staff. The validation of system interoperability could be limited to simulation testbed including C2 elements in the loop. The validation of technical level could be supported by a simulation.

Operational Level
Issues: Military Utility, Requirements Definition
Stake Holders: Military Users
Governing Doc's: CONOPS,TTPs (Tactics, Techniques, & Procedures)
Typical Approach: Top Down (Often Independent of Technology)

System Level
Issues: Architecture Design, Functional Decomposition
Stake Holders: Architects, System Engineers
Governing Doc's: Architecture Framework,CONOPs
Typical Approach: Bridge Between Operators &Techies

Technical Level
Issues: Data Content, Interchange & ProtocolReqt's
Stake Holders: Technologists, Industry
Governing Doc's: STANAGs, System Specifications
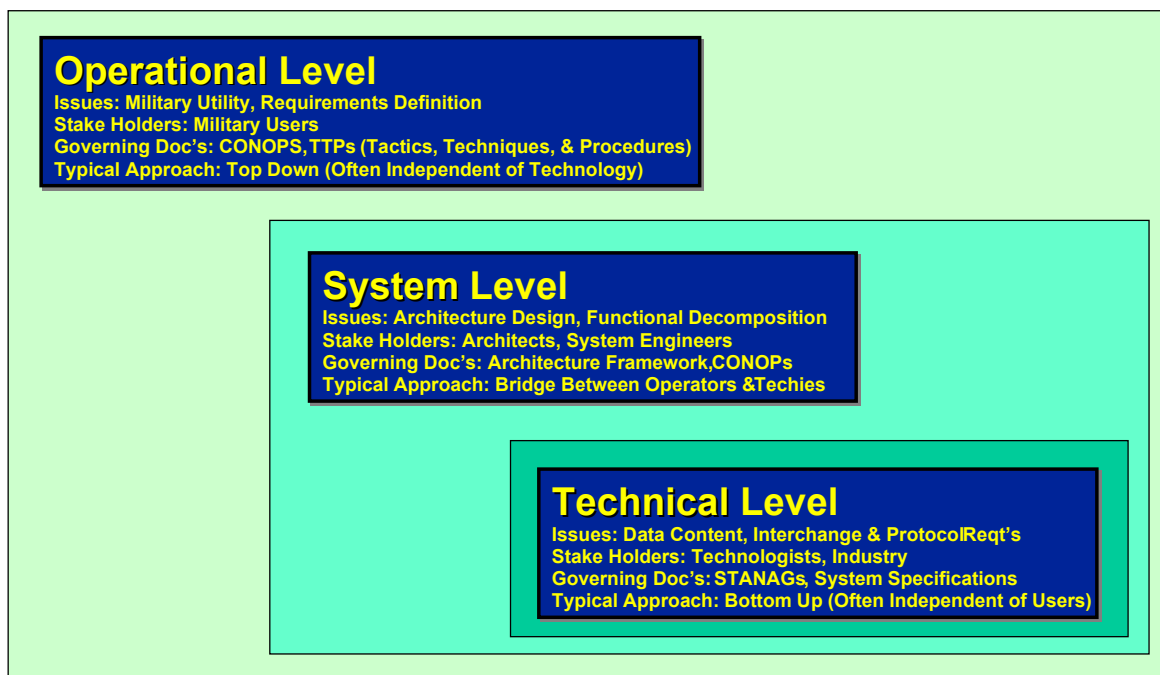Typical Approach: Bottom Up (Often Independent of Users)

Figure 2.2.-3: Validation at Different Levels.

Technical interoperability requires the use of real communications for C2 interfaces (non real-time data exchange and data-link information). Several C2 platforms connected by a WAN (Wide Area Network) and data-link network may be required. Preliminary system interoperability validation is required.

System interoperability requires the exchange of C2 information between the C2 elements of the EAD system and the verification that this information is correctly processed by these C2 elements. The simulation will be used to generate a synthetic environment (i.e. the threat and the missing EAD system elements). A platform of C2 software and simulations connected through a LAN (Local Area Network) are sufficient to demonstrate the system interoperability on various scenarios.

The **operational interoperability** includes operational personnel in the loop. A NATO/multinational exercise based on simulation and C2 platforms will be used in support of the horizontal and vertical interoperability validation.

It is generally accepted that EAD C2 interoperability is a necessity and that improvements are needed.

Current weaknesses include issues associated with:

- Interconnectivity (Technical interoperability)
  - Tactical data link implementations for EAD (differing versions and limitations in messages handled)
  - Introduction and testing of new hardware/software (high risk and cost)
  - Lack of global/unique standards for non-real-time information
  - Lack of infrastructure for interconnectivity tests

- Consistent processing (System interoperability)
  - NATO/Nations C2 functional inconsistencies
  - Common reference databases (for threats, etc.)
  - Lack of infrastructure for system tests
  - Combined and joint missions/scenario description

- Appropriate tactics, techniques and procedures and operations plan (Operational interoperability)
  - Lack of standard procedures and methodology for EAD
  - Cost and limitations of exercises

Depending on the abstraction level chosen for the analysis, models and simulations should either implement or represent real-life communication standard.

Implementing a standard will give the possibility to interface the model with a real system respecting that standard. Note that a model implementing a real-life standard can be used to evaluate the merits of evolution of the standard, or even to assure the interoperability of systems implementing different versions of the standard.

For some applications, it is not necessary or desirable to represent the data link at a very detailed level. Representing the data link using a behavioural model (a model that can determine the results of the use of the standard, without implementing it) can simplify models a lot, easing the development and reducing the computer power needed to run the models. Those techniques are mainly useful to represent large networks of systems, and to evaluate the compatibility of "concept of use" (or "rule of use").

Note that, for the EAD domain, the different modelling techniques exposed before can be used to develop the requirements for new data-link standards, create new data-link formats (or new messages in existing data link), or new standards for planning/tasking.

Chapter 3 – CONCEPTUAL MODEL OF THE EAD DOMAIN

3.1 INTRODUCTION

The objective of this task is to define the distributed simulation approach. This lends itself best to the participation of the nations and allows the maximum use of existing models and distributed simulation expertise.

The simulations should capture the four pillars of extended air defence (active defence, passive defence, attack operations, and Battle Management, Command, Control, Communications, and Intelligence (BMC3I)).

The capability should address multiple simulation fidelity levels (engagement, force-on-force, and campaign) to support interoperability requirements.

3.2 SIMULATION CONTEXT

Simulations will need to capture the appropriate interactions/behaviours for the elements they represent at their respective levels of fidelity. The simulations should capture unique characteristics and behaviours associated to extended air defence systems and the linkages between these systems. The simulations shall be capable of representing the EAD systems C2 and be flexible enough to demonstrate new concepts and capabilities.

The practical approach to get some grip on the complexity is to follow a 'checklist' that attempts to structure the problem and guides the selection of the required tools and models:

- What is the level of detail at which C2 is modelled (remembering that the "devil is in the detail")?

- Is a 'partial' simulation adequate (i.e. only simulate the function(s) of the network of systems where there may be problems)? If so, there is a need to determine the possible problems first.

- There may be a need to model the command and control doctrine in appropriate detail – this is often difficult with "standard" models which only build in one or two methods which may not be those being studied or used.

- Human reactions/performance must be considered, as the human is part of the real C2 system. Decide if there are men-in-the-loop, and if not, if the human model permits drawing conclusions on C2 interoperability.

- Does the application need to model the real C2 network (or at least part of it)? Architectures and networks will also influence capabilities and need appropriate modelling – tactical data links impose particular limitations that need taking account of. Design and management of tactical data links are issues for interoperability.

- Is simulation of the physical communication exchange necessary and/or is the "electrical interoperability" with real systems required (Hardware-In-the Loop or HIL)?

The simulations need to model the tactical data links to include, but not limited to Link 11/16/22. The modelling should take into account the appropriate functionality within a given system and be able to be transported via interfaces to other simulations. The simulation must also take into account the appropriate R2 rules for the given systems. The simulations need to be capable of both sending and receiving the necessary TDLs for a given system and must capture the complexity of the command and control linkages of individual extended air defence systems. Systems and Family-of-Systems CONOPS should be modelled to capture the working interoperability relationships between systems. Examples of

messages to be captured include, but are not limited to: Precise Participation Location & Identification (PPLI) (Indirect, Air, Surface & Land), Reference Point, Track Messages (Air, Ground & Space), Track Management, Data Update Requests, Command, and Status Messages (Engagement, Air Platform, Surface Platform & Land Platform).

The simulations capabilities should take into account the Measures of Performance (MOP) and Measures of Effectiveness (MOE) necessary to support NATO studies of extended air defence. Examples of extended areas of interest include, but are not limited to:

- Threat numbers and changes over time
- High value assets and changes due to threat capabilities
- Acceptable leakage rates and changes
- Defence architecture and changes over time
- New weapon changes
- New early weapon and surveillance systems
- Enhanced BMC3
- Enhanced counterforce capabilities

M&S development should focus on desired/required MOEs and MOPs within the EAD interoperability Schema. Examples of desired MOEs/MOPs might include:

- Shot opportunities (earliest, latest, etc.)
- Total numbers of shots
- Numbers of Kills
- Numbers of leakers
- Battle Damage Assessments (BDA)
- Detections (earliest, latest, numbers of, etc.)
- Missile wastage
- BMC3I effects (message loading, dropped tracks, etc.)

3.3   SIMULATION CONCEPT

Standardised interfaces are required to achieve simulation interoperability through linking of multi-national simulations. The simulations should be capable of exercising, communicating, and exchanging information via these interfaces. The simulations for example will need to be capable of processing tracks, performing correlation and fusion of tracks, performing appropriate reporting responsibility rules, and disseminating tracks via the appropriate BMC3I for acquisition and engagement of the threat. The methodology for performing these functions are expected vary from simulation to simulation.

3.4   SIMULATION ELEMENTS

The simulations should be capable of realistically modelling all of the necessary EAD elements. Examples include radios, radars, missile systems, BMC3I networks/systems, platforms (aircraft, vehicles, ships, satellites), BMs, and associated behaviours.

3.4.1   EAD Threat

Many studies suffer from lack of credible data on threat systems (particularly BMs). This lack of data can lead to low confidence in resulting study outputs particularly for systems that may depend on representation of boost-phase phenomenology or re-entry motion. Whilst obtaining data in these flight phases is difficult and may be subject to security and release problems, developing a common reference database would provide a consistent basis for future studies.

BMs should be modelled at a minimum 3 Degrees of Freedom (DOF) level. Radar Cross Section (RCS) and Infrared signature characteristics should be captured in order to adequately characterise sensors and the track data necessary to support interoperability requirements (covariance tables, probability of detection, detection times, etc.).

Modelling of EAD threat systems should also include ballistic missile transporter-erector-launcher (TEL)/Transloader behaviours (hide/reload/launch), its associated BMC3I and how this interacts with CCF missions.

The Extended Air Defence threat will be composed of short, medium and long range BM threats. The threat engagement processes should follow a typical kill chain process and take into account systems engagements from boost to terminal phase.

The Task Group will take advantage of potential sources of threat information like the NATO ALTBMD Feasibility Study consolidated database and the Missile Defence Feasibility Study database.

3.4.2   EAD Systems

Sensors

The characteristics to be addressed for the EAD representative systems should include accurate sensors (radar, infrared, passive RF, and intelligence sensors). These sensor models provide support for ISR, offensive, and defensive operations. Sensors to be represented may include:

- Early warning satellites
- Air defence radars
- Airborne ground surveillance
- External early warning radars (space, air & ground-based)
- Airborne early warning

The simulations should represent radar systems at anywhere from low-to-high levels of detail.

Jammers may need to be included together with their degradation on sensor systems. Similarly, in some applications, degradation of sensor performance through natural environmental effects may also be represented.

Weapon systems

System representations include space-to-space, space-to-air, air-to-surface, surface-to-air, surface-to-surface, and air-to-air weapons.

Missile system characteristics should accurately portray missile flight dynamics and capabilities. Pk can be captured via look-up tables and/or flat files. Federations of models may provide interfaces to engineering level fidelity of models where practical.

Air-to-surface engagement modelling can incorporate free-fall bombs, anti-radiation missiles (ARMs), and other Air-to-Surface Missiles (ASMs).

Modelling of **surface-to-air** engagements allows representation of SAM and gun systems in engagements against both aircraft and tactical missiles.

Air-to-air engagement modelling can incorporate both IR, semi-active, and active missiles.

The **surface-to-surface** modelling can incorporate both BM and the cruise missile weapon types.

Figure 3.4-1: Example of Offensive and Defensive Systems in an EAD Environment Models.

BMC3I

The ACCS will serve as the basis for NATO EAD BMC3I. The ACCS has an open and flexible architecture. This assures coherence with the EAD against the classical air threat.

EAD operations, especially BM defence, may extend beyond member nations' borders. This requires commonly understood procedures and established, mutually agreed upon Rules of Engagement (ROE).

There is no adequate EAD BMC3I structure within NATO to accommodate the full spectrum of the EAD threat. The agreed Level of Operational Capability 1 (LOC 1) of the ACCS will be a major improvement to counter the classical air defence threat and will provide a limited capability to counter BMs.

Although effort is underway within NATO to provide full BM capability, significant EAD BMC3I deficiencies currently exist. Within EAD, the Deployable ACCS Component will have to contribute to operations within the Alliance as well as outside. It is worth noting that ACCS will provide an enhanced capability to interface with maritime assets.

Communications

The purpose of this conceptual model is to define the simulation requirements necessary to model and analyse Command & Control (C2) Interoperability functionality to include: Tactical Data Links (TDLs), air, ground, and space system requirements, command chain messaging, Reporting Responsibility (R2) rules, systems networks and devices, and interoperability capabilities and impacts.

The simulations should be capable of explicitly and implicitly modelling the C2 elements necessary to support extended air defence systems interoperability requirements of systems from different national origins and capabilities.

Communication systems and formats have to be modelled at the appropriate levels of fidelity, and sufficient detail to meet study requirements. Message network loading and content should also be modelled by the simulations.

The detailed simulations should be able to model communications down to individual radios and their specific characteristics (BAUD rate, RF, etc.). The simulations shall be capable of accurately representing the tactical data links necessary to support C2 Interoperability analyses.

Communications modelling should include networks, messages, and devices. The networks would specify which players will attempt to communicate and the types of information exchanged. The device modelling allows the modelling of the RF propagation, capturing the impact of relative geometry, terrain, and jamming.

3.5   SCENARIOS

The development of scenarios that are consistent, meaningful and have political and military credibility is not trivial. Furthermore, there are various levels of description of scenarios. At a high level the geographical region is identified, the major combatants and their available forces, and the overall aims of the military endeavour (for both sides) are laid down. At a much more detailed level the lay down of all of the entities, the sequence of incoming threats (at least for the first wave of threats) and the whole offensive and defensive orders of battle, and command structure is laid out in considerable detail.

Currently there are few standards to help with describing scenarios such that they can be used in different models. Thus re-implementing a scenario developed in one model in another may require considerable effort.

3.6   ENVIRONMENT

Natural environments are an important aspect of extended air defence and BMC3 and should be taken into account of as part of the simulation architectures. Natural environments should include terrain, atmosphere, and weather. The terrain impacts flight and movement, sensor coverage, and communications capabilities. Standard atmospheric models are used for aircraft and missile flight modelling and RF propagation. Weather modelling is limited to uniform layers of clouds, particulants, etc. over the entire scenario. The effects can be captured either explicitly or through modelling of the anticipated impacts in the form of degraded systems performance.

3.7   FEDERATION CONCEPTUAL MODEL (FCM)

In order to develop the Federation Conceptual Model, the following questions have to be addressed:

- What are the overall objectives of the target federation (CTJF (exercise)/JFACC/ACCS (experiments) and at what levels must C2 be modelled?

- What are the C2 interoperability objectives for EAD
    - Levels of detail for C2 modelling
    - C2 doctrine considerations
    - Human performance/reactions (human decision process)
    - Real C2 modelling requirements (architectures, networks, TDLs)
    - Physical modelling of communications
    - How much simulation is required

- What are the CTJF critical thrusts/requirements and how are they updated and how frequently (biannual update/surveys)

Chapter 4 – M&S INTEROPERABILITY: STATE OF THE ART

4.1   INTRODUCTION

The aim of this section is to describe current state of M&S for EAD, both representative applications/tools and the involved technology are discussed.

4.2   CURRENT USE OF M&S IN EAD

Simulation tools and models for air defence analysis come in all shapes and sizes. Simulation models range from high fidelity one-on-one missile simulation programs to highly flexible planning aids.

The different application areas for which M&S can be used are categorised according to the accepted NATO terminology (e.g. in the NATO M&S Master Plan):

- Prototyping/Research

- Procurement Decisions

- Defence planning

- Training/exercises

- Support to operations

This approach reflects the concept that M&S can be used to support all phases of the life-cycle of a product or system (Figure 4.2-3). Maximum re-use of the M&S assets is achieved when the same models, tools or software can be applied for multiple phases. Apart from the obvious cost and efficiency benefits, stronger re-use also results in more confidence in outcome and conclusions due to wider verification and exposure of a model or tool.

The cyclical process described in the figure is applicable to the EAD domain also. The requirements of the EAD system are initially generated based upon the results coming out of studies and analysis activities. The requirements are then implemented in prototype software where they can be explored for technical feasibility in detail. The emerging requirements (as implemented in the prototype software) are then put in front of operators in realistic experiments and exercises to evaluate them with respect to their operational utility and usefulness. The process repeats with more and more insight and detail being developed after the completion of each phase. With this approach, BMC3 requirements can be generated quite rapidly even in a complex mission area like missile defence.

HLA supports this vision of re-use of distributed simulation components by acknowledging that no single simulation can serve all needs, but that 'components' developed for one simulation can be re-used in other phases of the lifecycle or in other domains. That principle is realised by providing a well-defined usage process (like HLA's Federation Development and Execution process or 'FEDEP') and providing a well defined architecture that separates 'infrastructure services' from 'application code'.
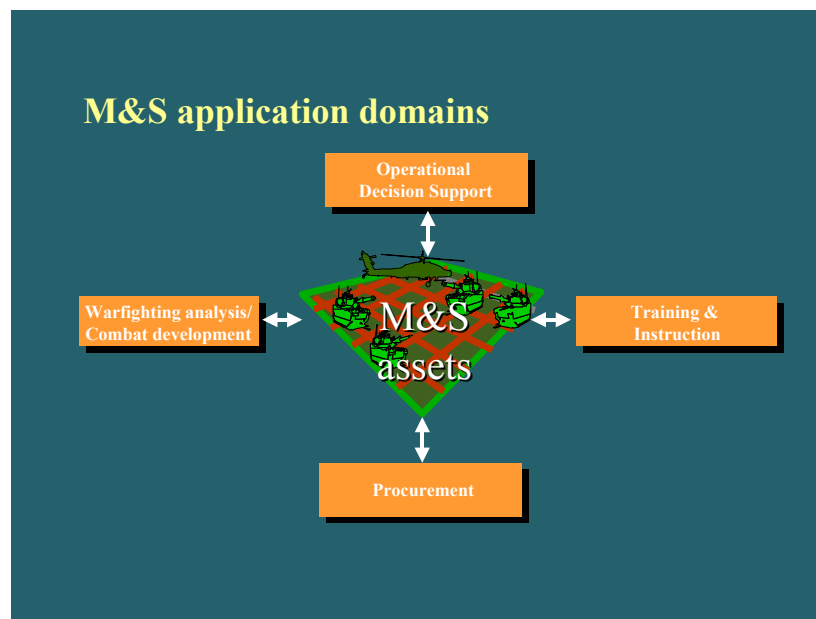
Figure 4.2-1: M&S Support in all Phases of the Life-Cycle.

The TG queried the M&S community to determine the appropriate models to be considered for the EAD relevant C2 interoperability requirements. Selection was based on validation, verification and accreditation of each model, community acceptance of the models in their respective areas, and each model's strengths and weaknesses based on levels of fidelity, functionality, and supporting data for representing the C2 interoperability capabilities. The overview given in the appendices only intended to provide a global description of available planning, training and/or analysis tools. The overview is not exhaustive or complete. Where possible, the model's capability to interoperate with other tools at different levels of aggregation/command level is discussed. Note that the TG also included 'exercises' in its overview. In a sense, an exercise can be seen as a model of reality. The link between exercises and models is often needed as one or more participants in an exercise are usually simulated (e.g. missiles).

4.2.1   Levels of Simulations

The Air Force Modelling and Simulation analysis toolkit (http://www.xo.hq.af.mil/xoc/xoca/afsat/) is an AF-approved collection of models and simulations, which distinguishes the following categories.

Campaign Level Simulations:

Campaign Level simulations provide information and insights to senior decision makers and answers questions involving force structures, operational concepts, and military capabilities. Examples are:

- CAPS
- MDWAR
- THUNDER

Force on Force (Mission) Level Simulations:

Force on Force (Mission) Level simulations reflect the ability of a multi-platform force package to accomplish a specific mission objective, which might span a period of hours. In conjunction with human participation, mission level simulations may be used for wargaming, training, and tactics development.

Examples are:

- EADSIM
- SEAS
- SUPPRESSOR
- POSEÏDON
- J-ROADS

Engagement Level Simulations:

Engagement Level *simulations* evaluate effectiveness of an individual platform and its weapon system against a specific target or enemy threat system. Examples are:

- BRAWLER
- EADTB
- ESAMS
- MOSAIC

Details of these simulations may be found in Appendix B.

4.3   M&S INTEROPERABILITY TECHNOLOGY

The TG recognises that linking or federating of the needed models and simulations best achieves flexible and effective M&S support for EAD. Typical interfaces might include DIS, HLA, and SIMPLE. Any of these interfaces will require the development of a 'mapping document' describing what objects and information will be shared between the models and simulations. The 'mapping document' is also known as the 'Datamodel'. The High Level Architecture (HLA) uses the Federation Object Model (FOM) to document the Datamodel. The Datamodel development effort may include additional standards (e.g. representation of Datalinks and C2 interoperability) to support the identified requirements.

No matter how superior sensors and weapon systems of any future TBMD system may be, their effectiveness will be reduced when they can not interoperate and provide the associated BMC3I system with the information necessary to complete their task. The TG examined the most common interoperability models and briefly reports on these in the sections below.

4.3.1   DIS

The first well established interoperability standard that appeared was the Distributed Interactive Simulation (DIS) protocol. DIS is an IEEE standard for real-time simulation systems to exchange information using Protocol Data Unit (PDU) formats to send several types of simulation information.

PDUs are the generic name for the various simulation data record formats used by the DIS protocol. PDU record formats include the Entity state PDU, Fire PDU, Detonate PDU, IFF PDU, Send PDU, Simulation Start PDU, etc. (See http://www.pitch.se/fmv/dis-items/Pduindex.htm)

DIS is widely used and many simulation systems support the standard. However, many applications have added extensions to the PDUs to allow for specific information that was not covered by the DIS standard. This resulted in user defined PDUs hampering interoperability and involving extensive integration efforts when new federations are being developed. Proprietary additions are not likely to become part of the DIS standard since development of the standard has been halted in favour of the High Level Architecture standard.

4.3.2   HLA

The Defence Modelling and Simulation Office (DMSO) is the lead for modelling and simulation (M&S) activities within the U.S. Department of Defence. This organisation is charged with maximising the efficiency and effectiveness of M&S efforts across the DoD and fostering interoperability and reuse of models and simulations. DMSO projects include the development and promotion of HLA. (Web Site: http://www.dmso.mil/)

The High Level Architecture (HLA) is a general-purpose architecture for simulation reuse and interoperability. HLA is increasingly providing a distributed simulation framework for new simulations. HLA is defined by a set of rules, an interface specification, and an object model template. HLA is not a standard but only a methodology for developing standards. There are many different simulation standards being developed using the HLA architecture. DMSO has developed an initial suite of HLA software and tools for developing simulation standards including the Federation Object Model or FOM. The FOM is an identification of the essential classes of *objects, object attributes,* and *object interactions* that are supported by a High Level Architecture federation. In addition, optional classes of additional information may also be specified to achieve a more complete description of the federation structure and/or behaviour. One of the main components of HLA is the Run-Time Infrastructure (RTI).

The RPR FOM is a 'translation' of the DIS protocol (IEEE Standard 1278.1) into an HLA Federation Object Model. Information about this FOM is available from SISO. The FOM, SOM and RTI are components of the HLA simulation communications methodology. There are a number of FOM development efforts underway within DOD (e.g. RPR-FOM). The JTLS FOM could also be of interest mainly for vertical interoperability (available from NC3A).

The following are some common HLA related acronyms:

> FEDEP – Federation Execution Development and Execution Process
>
> OMT – Object Model Template
>
> FOM – Federation Object Model
>
> SOM – Simulation Object Model
>
> RTI – Runtime Infrastructure
>
> RTI NG – RTI Next Generation (After Version 1.3)

(Web Sites: http://hla.dmso.mil/ and http://www.sisostds.org/doclib/cat_display.cfm?id_number=13)

The fact that HLA is available as a common standard to simulation interoperability should not give the false impression that HLA is a 'magic bullet'. Simulation developers still need to sit down and work out the details of the federation. Defining the FOM is one important element, but many others remain and are part of the FEDEP. All relevant interoperability issues are generally captured in the 'federation agreements'. Examples of such agreements are:

- Type and Version of RTI to be used

- Type and selection of RTI services to be used (e.g. time-management aspects)

- Publish and subscribe responsibilities of federates

- Federation management (e.g. starting and stopping the federation)

The TG recommends that a tailored version of the FEDEP is developed as part of the proposed EAD C2 architecture. This FEDEP should also include the federation agreements as derived from best practice experience.

DMSO has carried the development of HLA until it was ready for approval as an IEEE standard. This standardisation was achieved as IEEE 1516. Subsequently, DMSO has reduced its involvement and has withdrawn from supporting the development of public domain RTIs and other HLA tools. Commercial versions are now available that comply with IEEE 1516 (e.g. Pitch and Mak). The advantages for the user are better support and more competition with respect to features of different RTIs. The disadvantage is higher cost in licences and maintenance.

The future tasking and role for DMSO is under revision and consequently other forums have become more important for setting HLA standards. The most important organisation is the Simulation Interoperability Standards Organisation (SISO).

SISO focuses on facilitating simulation interoperability and component reuse across DOD, other government, and non-government applications. SISO seeks to provide a forum for the interchange of new ideas, concepts, and technology across the broad modelling and simulation community; to disseminate these ideas; to educate M&S practitioners and sponsors regarding their implementation; and to support the development of standards, practices, and guides for use in various applications. As part of this effort, SISO sponsors activities, which provide education, technology exchange and standards activities for the modelling and simulation community. SISO sponsors two Simulation Interoperability Workshop (SIW) conferences in Orlando each year. These conferences are major M&S events. (Web Sites: http://www.sisostds.org/)

Current SISO activities relevant to MSG006 are Study Groups on the definition of FOMs that represent Tactical Datalink information and a Study Group involved in the issues relating to C2 and Simulation interoperability.

4.3.3   SIMPLE

The Standard Interface for Multiple Platform Link Evaluation (SIMPLE) is a Ground telecommunications-based network (ISDN, with encryption) for platform interoperability testing of Tactical Data Links. SIMPLE was developed by Digital Wizards/SPAWAR as a NATO initiative and was sponsored by NC3A. SIMPLE supports: TDL Messages, Scenario data (DIS PDUs), Test management and control data. Packet types include: Link4, Link11, Link16, Link22 and DIS PDUs. SIMPLE is available as STANAG 5602 (draft edition2).

The Tactical Data Link Interoperability Testing Syndicate (TDLITS) was established by the NATO Interoperability Environment Testing Working Group (NIETWG) and first met in October 1999. The Syndicate has been given the task by the NIETWG of looking after all aspects of international TDL IO Testing until the NATO Interoperability Environment Testing Infrastructure (NIETI) Management Structure is implemented and can take over the task. The Syndicate took over from the Standard Interface for Multiple Link Evaluation International Data Link Interoperability Test Squad (SIMPLE IDIOTS). Between February 1996 and February 1997 this group defined a single interface standard to support TDL IO Testing, STANAG 5602, and in April 1999 successfully tested this standard during the SIMPLE Demonstration and IO Test.

SILVER is a tool, developed by DERA/QinetiQ, that provides a complete implementation of STANAG 5602 (SIMPLE). PC based with commercial-off-the-shelf interface cards, SILVER supports secure transfer of TDL, DIS and other messages over ISDN lines between dispersed platform rigs, scenario generators, test management and analysis sites and virtual/real world interfaces.

Web references to SILVER and various other TDL tools:

http://www.tacticaldatalink.com/tools.htm

4.3.4   Datalinks over DIS and HLA

Various non-interoperable datalink implementations have emerged as DIS standards for the implementation of tactical datalinks. For example, five different TADIL-J/JTIDS standard have evolved over the last 10 years (JTIDS = Joint Tactical Information Distribution System). There are immediate and overdue operational requirements for existing military simulations to exchange TADIL-J/JTIDS data using a single interoperable method. As military distributed simulation evolves further in mission scale and complexity, other tactical datalink implementations need to interoperate. At the 2001 I/ITSEC a team led by the Theatre Air Command and Control Simulation Facility (TACCSF), Kirtland AFB, formed a Simulations Tactical Data Link Standardisation kick-off meeting. Approximately 50 people attended this meeting with representation from industry and government. A draft implementation proposal was put forth by TACCSF. The group recommended to continue any additional standards development work under the SISO umbrella, and formally become a SISO study group for the Spring 02 SIW.

The objective of the SISO Tactical Datalink Study Group (TDL-SG) was to develop a reference standard for the simulation of Tactical Datalinks within the current DIS framework, with an eye towards implementation in High Level Architecture. The first task was to develop a reference standard for Link-16/JTIDS. Subsequently, the study group will select and study other tactical datalinks for which there is a current or future operational need in simulations. The Link16 Reference Standard development was performed by a 'product development group'. The Reference Standard implements JTIDS within DIS by using the Transmitter and Signal PDUs. The corresponding HLA version is presented in the form of a Base Object Model (BOM) that may be incorporated into an existing system FOM. The current draft (Ref [6]) will be submitted to a balloting process by the end of 2003.

POC: Adin Burroughs, Email Address: adin.burroughs@kirtland.af.mil

Documents : http://www.afams.af.mil/doclib/doclib.cfm?AFAMS_RID_1000641

Web references to NATO's TDL interoperability testing workgroup:

http://www.tacticaldatalink.com/

The TG notes that it is necessary to define not only the TDL type (e.g. Link16), but also the exact version that is to be used (including possible revisions). Furthermore, the set of messages that are to be used should also be defined. The example shown in Table 4.3-1 illustrates the J-Messages that are required in the 2004 JPOW-08 exercise. These requirements enable the simulation models to interact in a realistic way with the live systems (e.g. PATRIOT via FMS-D) in the JPOW-exercise. This list may serve as an example for TDL Interoperability needs for a typical EAD related simulation environment.

Table 4.3-1: Overview of J-Messages Required for the 2004 JPOW-08

No.	Type	Direction	Need
J2.0	Indirect PPLI	Receive	Required
J2.2	Air PPLI	Receive	Required
J2.3	Surface PPLI	Transmit/Receive	Required
J2.4	Subsurface PPLI	Receive	Desired
J2.5	Land Point PPLI	Transmit/Receive	Required
J3.0	Reference Point	Transmit/Receive	Required
J3.2	Air Track	Transmit/Receive	Required
J3.5	Land Track	Transmit/Receive	Required
J3.6	Space Track	Transmit/Receive	Required
J7.0	Track Management	Transmit/Receive	Required
J7.1	Data Update Request	Transmit/Receive	Required
J7.2	Correlation	Transmit/Receive	Required
J7.3	Pointer	Transmit/Receive	Required
J7.4	Track Identifier	Transmit/Receive	Required
J7.5	IFF/SIF Management	Transmit/Receive	Required
J7.6	Filter Management	Transmit/Receive	Desired
J9.0	Command	Transmit/Receive	Required
J9.6	Engagement co-ordination	Transmit/Receive	Required
J10.2	Engagement Status	Transmit/Receive	Required
J13.2	Air Platform Status	Receive	Required
J13.3	Surface Platform Status	Transmit/Receive	Required
J13.5	Land Platform Status	Transmit/Receive	Required

4.4   M&S POLICIES

Interoperability technology and standardisation efforts as described above can not be successful unless underpinned by good management. Standardisation is hard and requires initial investment in time and resources before its benefits become visible. The US government and other nation's governments and agencies have recognised this fact and provided management guidelines and policy documents known as Modelling and Simulation Master Plans (MSMP). The following are web links to various MSMPs:

- DOD Modelling and Simulation (M&S) Master Plan: http://web7.whs.osd.mil/html/500059p.htm
  DOD M&S Master Plan Special Interests: http://www.msosa.dmso.mil/msmp/

- Air Force M&S Master Plan: http://www.afams.af.mil/webdocs/afmsmp/

- Army M&S Master Plan: http://www.amso.army.mil/mstrpln/

- Navy M&S Master Plan: http://navmsmo.hq.navy.mil/policy/plans/navy/

- NATO M&S Master Plan: http://www.dmso.mil/documents/policy/nato_msmp/index.html

4.5   ANALYSIS OF CURRENT APPROACHES

The objective is to model C2 for systems and study how those systems interoperate both with weapon systems (for example) and also amongst themselves (BMC3I to BMC3I system). The central question is:

How can the complexities of the real world be mapped on to a (federation) of models, without introducing "simulation artefacts" and also still helping to provide answers to the essential questions?

The Task Group performed a brief analysis of current approaches to modelling C2 interoperability for EAD and illustrated some of the common pitfalls in order to make recommendations for improvements to support future requirements. The most common M&S approaches for EAD are:

- Integrated simulation of a network of systems.

  By default the internal models are interoperable, often these systems are big and impossibly complex, or too simplistic and high level. Without support from developers or access to internal details it is difficult for the users to assess the accuracy of the conclusions drawn from the simulations. Modifications or additions to the simulation may also be problematic without support from the model owners.

- Distributed simulation of a network of systems.

  Each simulation models one system, simulations are networked. Clearly, 'ad-hoc' protocols for simulation communication is not workable. A communication standard is needed (e.g. DIS/HLA with appropriate data model). Common environment databases are needed and it must be verified that the effect of the environment is equivalent in all the models. Finally, the need exists to assess "fair fight", the coherency of the different system models. In general it is possible for users to add/replace models as required by the particular application.

- Hardware-in-the-loop.

  This approach is a variation of the previous with Hardware (or real operational software) in the loop (need to build the system before assessing the interoperability).

4.6   M&S LESSONS LEARNED

The TG briefly evaluated experiences and lessons learned in previous analyses, exercises, and training activities.

During the fall of 2002 NC3A and TNO were involved in Cannon Cloud '02 and joined in a project to implement interoperability between EADSIM and JTLS [Ref 9]. EADSIM was required, because JTLS could not represent single PATRIOT units and accurate TBM trajectories. Using EADSIM, TNO brought the TBM play into Cannon Cloud for AIRNORTH and the RNLAF.JTLS provided 'launch messages' to EADSIM, which computed the trajectory, provided trajectory data to JTLS for display and generated intercept or impact data that was relayed to JTLS. The JTLS tool would then use this information for use in assessment of the mission. Both EADSIM and JTLS support HLA in more or less comprehensive ways. The FOMs however are different and needed to be streamlined.
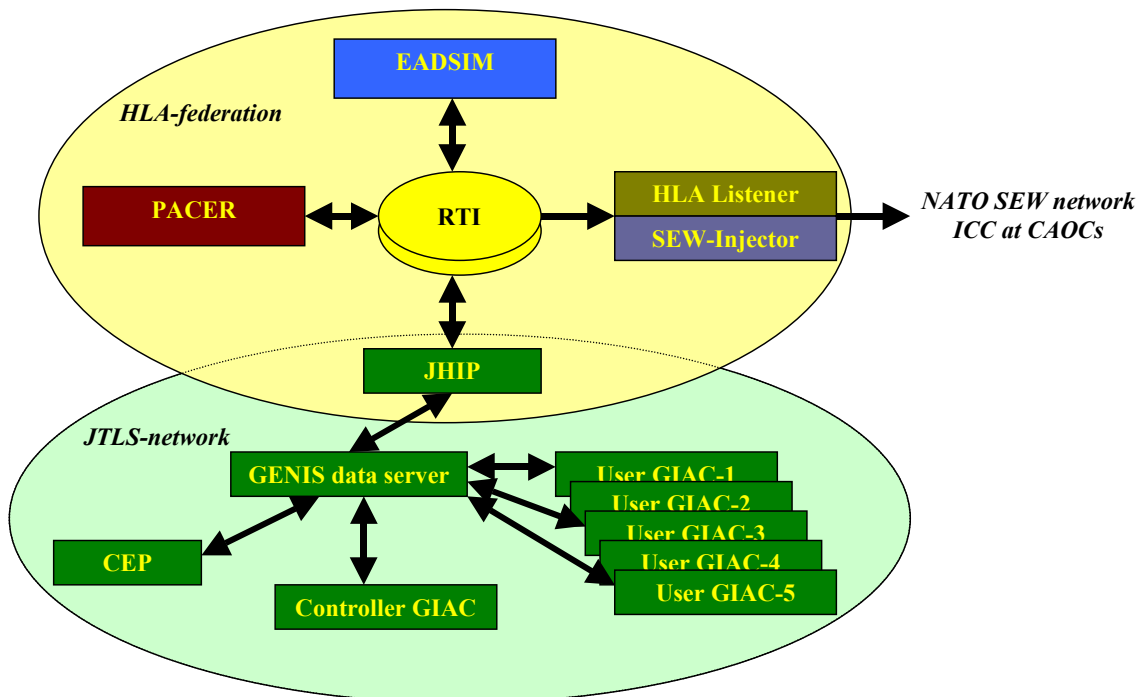
|				
CEP	=	Combat Event Program	JHIP =	JTLS HLA Interface Program
EADSIM=		Extended Air Defense Simulation	JTLS =	Joint Theater Level Simulation
EHIP	=	EADSIM HLA Interface Program (new)	PACER =	a federation time management tool
GENIS =		JTLS HIP Data Holder/Server Process	RTI =	Run Time Infrastructure
GIAC	=	Graphical Interface Aggregate Control	SEW =	Shared Early Warning
HLA	=	High Level Architecture		
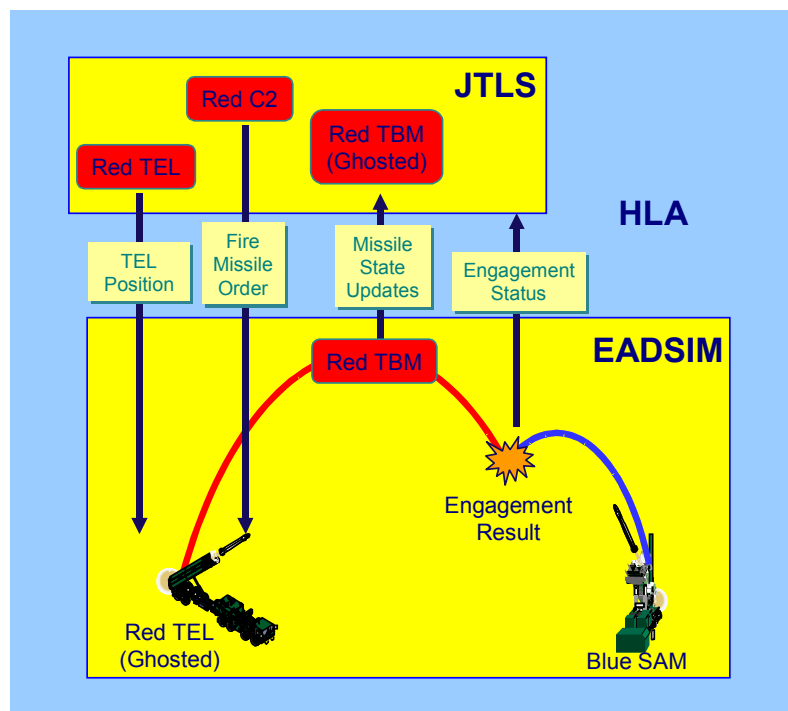
Figure 4.6-1: JTLS-EADSIM Federation at Cannon Cloud '02.

Based on this experiment and JPOW the following lessons learned were defined (which are representative of a wide range of similar experiments):

- Data Distribution Management is crucial to minimise number of entities that are processed by one computer;

- The FOM agility problem can be solved, but it's not an easy one;

- The EADSIM-JTLS link now works, but linking EADSIM to another application requires the same amount of work again; (because of the absence of Reference FOMs);

- Link 16 capability is crucial to realistically exercise with live and virtual players;

- DIS can be good enough (i.e. HLA is not needed at all times);

- Stable models that keep running despite data errors and or unexpected conditions are preferable to unstable models that crash and require the model to rejoin the federation (which may take several minutes during which other participants are paused); and

- Only a very small part of EADSIM SOM was used to get the required result, full use of the FOM will increase the problems by an order of magnitude.

The second example is the NATO Distributed Multi-National Defense Simulation (DiMuNDS 2000) federation demonstrated at the 2000 M&S conference (Figure 4.6-2). This federation was a technical demonstrator for CJTF staff training and was developed under the auspices of NMSG.
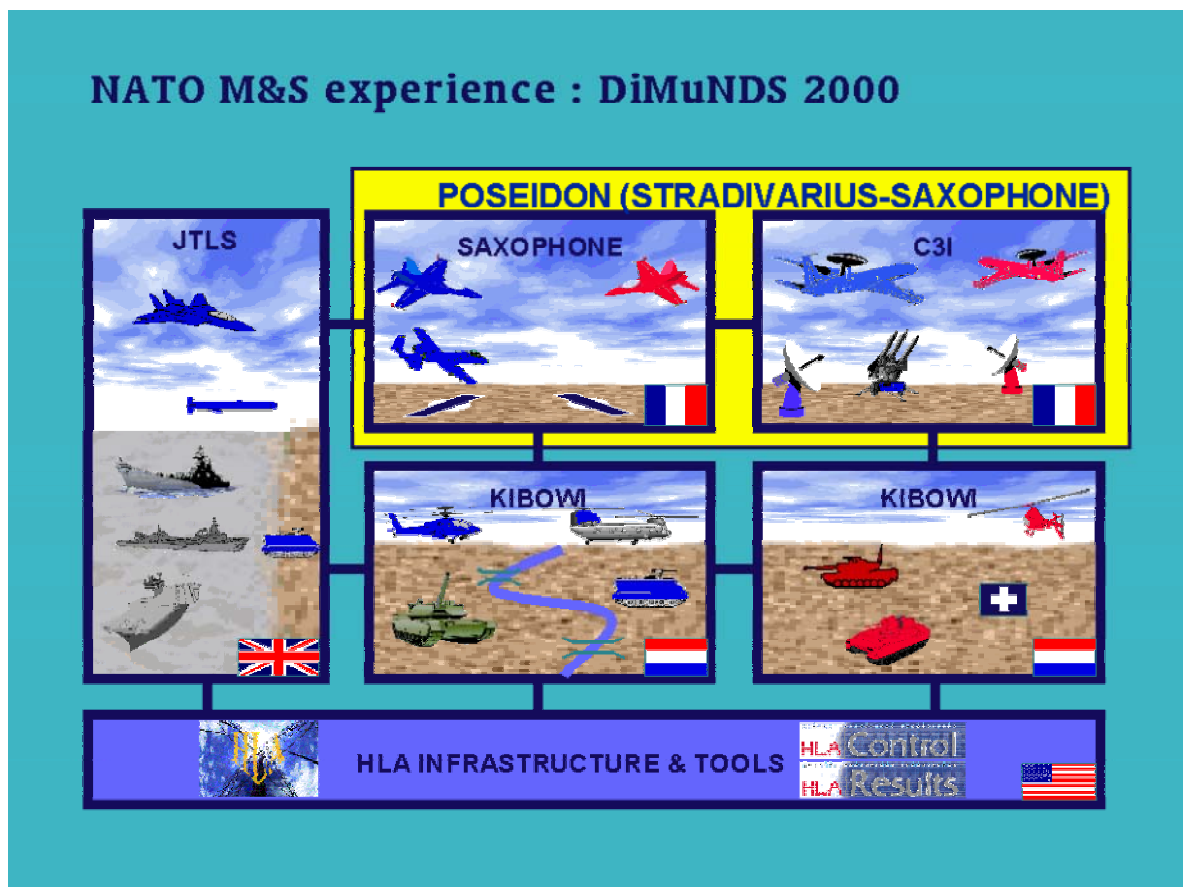

Figure 4.6-2: DiMuNDS 2000 Federation.

Ground forces were represented by two (separate) instances of KIBOWI (Netherlands). Air forces (especially air defence and C2) were represented by STRADIVARIUS-SAXOPHONE (a POSEIDON application, developed by France). JTLS was used to provide boundary military conditions (including Cruise Missiles fired from sea).

NATO C3 Agency acts as the Federation Manager for the DiMuNDS 2000 project, supported by additional staff from The Netherlands Organisation for Applied Scientific Research (TNO) and Virtual Technology Corporation (VTC). The DiMuNDS 2000 federation management effort was jointly funded by NC3A and DMSO.

In conclusion, the TG finds that the transition to HLA is the current technical and political state of the art for M&S. However, migration of existing models is often slow for reasons of funding or lack of a commonly accepted FOM. This results in a situation where models and simulations will exist in a mixed DIS/HLA and or proprietary form.

The general M&S lesson is that standardisation is needed to allow re-use and that this is not possible without a good plan and some pressure.

Chapter 5 – MODELLING AND SIMULATION ISSUES AND RESPONSES

5.1   INTRODUCTION

In Chapter 2, we have addressed the major issues associated with C2 in the EAD environment. Essentially we illustrated that this is an evolving and significant challenge involving many different types of entities and differing levels of interoperability.

- Interconnectivity (Technical interoperability)
  - Tactical data link implementations for EAD (differing versions and limitations in messages handled)
  - Introduction and testing of new hardware/software (high risk and cost)
  - Lack of global/unique standards for non-real-time information
  - Lack of infrastructure for interconnectivity tests

- Consistent processing (System interoperability)
  - NATO/Nations C2 functional inconsistencies
  - Common reference databases (for threats, etc.)
  - Lack of infrastructure for system tests (as above)
  - Combined and joint missions/scenario description

- Appropriate tactics, techniques and procedures and operations plan (Operational interoperability)
  - Lack of standard procedures and methodology for EAD
  - Cost and limitations of exercises

In Chapter 4 we have discussed the state of the art in simulation and modelling. The major development in recent years has been the development of DIS and HLA to support the linking of disparate, distributed simulations into a federated simulation. This is not just an academic exercise in distributed computing; there is a very practical reason for the use of federated simulations. The scope of EAD modelling is such that one monolithic model would be extremely large and complex and in many cases would not even be desirable. In a context where multiple companies or multiple nations wish to conduct simulations, there may well be a desire to avoid disclosing internal details of simulations and so each individual simulation federate becomes essentially a "black box" plugged into the overall federation. Furthermore, in some cases, these "black boxes" may be replaced for some exercises with emulations or real system elements. Thus a simulation may comprise a mix of simulated and real components co-operating in a federated environment. The challenges in achieving this relate primarily to establishing appropriate FOMs and SOMs that individual models can sign up to.

5.2   TECHNICAL INTEROPERABILITY

5.2.1   Tactical Data Link Implementations for EAD

Testing and verification of tactical data link implementations is difficult – we can do some of it very effectively in a simulated environment. The necessary condition is to have a reference interface for our simulation tools that represents the data link. This will support some level of testing within the simulated environment before moving to the real world. If there are proposals for changes or new messages, these can be developed and tested in the simulation prior to real world.

A preliminary study is required to fix the reference interface and subset of messages. The SISO proposal on implementation of Link16 in HLA is part of the answer, but it still needs validation in practical experiments.

5.2.2   Introduction and Testing of New Hardware/Software (High Risk and Cost)

New hardware and software can be tested within a simulated environment and tested via datalink interfaces and/or DIS/HLA interfaces. Useful components are "black boxes" that can interface between the simulated and real world. Some of these are DIS based, which in future we would like migrated to HLA. These translations could either be between normal elements of HLA FOM (e.g. entity state used for threat propagation) or from TDL FOM and real-world TDL. The discussions and diagrams in Sections 1.3 and 4.3.4 illustrate these relations.

5.2.3   Lack of Global/Unique Standards for Non-Real-Time Information

Exercise planners are highly encouraged to adopt XML formatting to facilitate and expedite the sharing of scenario data, threat parameters, deployments, etc. Once established, a centralised distribution methodology would allow developers to automate the extracting of relevant simulation data. Such a methodology should reduce the manpower to make dynamic changes by commanders.

The XML scheme would provide a tailorable non-rigid morphable standard for scenario distribution and implementation. Such a scheme would be defined (top down) by the CJTF non-real-time and similar planning documents and specified (bottom up) by FOM considerations.

XML formatted documentation would be the baseline for scenarios (etc.) and all of the different tools could be responsible for accessing and converting to any local formats. The XML would remain the single authoritative baseline. XML can be easily accessed or created by collaborative planning tools and then visualised.

5.2.4   Lack of Infrastructure for Interconnectivity Tests

Different nations are at differing levels of maturity in building infrastructure to support tests. There are opportunities for co-ordinating these efforts to ensure that in the future it is easier to bring components together for testing. As part of this approach, one needs a common FOM, use of XML, etc. One could also include a common federation development procedure, which will be tailored to the EAD domain to expedite multinational co-operation.

5.3   SYSTEM INTEROPERABILITY

5.3.1   NATO/Nations C2 Functional Inconsistencies

The major challenges arise from the operation of NATO infrastructure, for example, ACCS, and national systems such as weapon systems or national command systems. It is this problem that needs to be explored to address the interoperability challenges and to demonstrate increases in effectiveness that can be achieved by improved interoperability.

Datalinks present their own challenges. In particular, can the systems communication at a "syntactic" level? Do the various systems on the datalink interpret information consistently amongst themselves?

May some special/new mode of operation improve the efficiency of the system of systems in the realm of EAD? The specials needs of EAD are:

- for TBM, accurate (maybe more accurate that standard Air Tracks) data should be sent very quickly from the sensors to the weapon systems, perhaps bypassing standard flow of data.

- Need data fusion from more sensors of different nature than standard Air Defence (IR satellite, drone with optical sensors, long range surveillance radar of fire control radar)

To address all of these issues will require intelligent and clever abstraction and application of models. Modelling whole of ACCS is daunting and even if achieved may not easily enable the key questions to be answered; it is more likely one needs to model an appropriate sub-set that will answers the questions faithfully and affordably.

Given that interoperability requires not just communication, but coherent tactics, techniques and procedures, one needs to model the various command and control processes at appropriate levels to reveal inconsistency or interoperability problems associated with, for example, mismatched procedures.

Communications modelling present particular challenges. There are detailed communication models that can represent a variety of communication systems at fine detail and sometimes these are the correct tools to use. However, in other cases, such detailed modelling may be overkill that ends up dominating the simulation inappropriately. On the other hand, failure to model communication in appropriate detail may well ignore the very detail that is critical to understanding why and when the real-world systems will or will not perform adequately.

5.3.2   Common Reference Databases (for Threats, etc.)

Technically the implementation of a common reference threat database is not difficult, although there may be interesting discussions between the experts as to the performance and behaviour of some of the threat systems. However, even with the availability of such a common database, the implementation of threats in the various models is unlikely to be a trivial exercise. For example, trajectories for a particular ballistic missile may differ considerably between two models even when the launch, impact and other reference points are chosen consistently. A potential pair of threat sources would be the NATO TMD Feasibility Study and the Missile defence Feasibility Study.

For the purpose of demonstrating anything with models, we need to be able to extract the relevant data from the models, and to record this data (in a centralised database, for example) for later analysis. Only by globally inspecting data from the connected models can we reach conclusions on interoperability. The interface with the common database should be part of the standards (note that the database could be reached through messages of the federation).

With a "standard" logging database, (standardised access and standardised data to be logged), a set of standard tools can be created, that can diagnose interoperability problems and capacity for systems. Even if definite answers cannot be given at the model level, this set of helper tools can help to identify the most likely sources of problems.

5.3.3   Lack of Infrastructure for System Tests

See 5.2.4.

5.3.4   Combined and Joint Missions/Scenario Description

We need to establish means for information and scenarios in one model to migrate to another. Inevitably there will be a need for tailoring, but the ideal would be to achieve as much as possible through the use of common descriptions and script files. Differences in the models will lead to specific challenges. For example, there are number of ways in which different simulations represent the earth ("flat", spherical,

ellipsoid, WGS-84 model, with or without terrain and culture data) and its motion (rotating/non-rotating). These differences will affect a whole range of aspects of the simulation, such as visibility, the shape of "ballistic" trajectories and so on. In addition, co-ordinate reference systems (earth-centred inertial, earth-centred rotating, for example) may also add complexity. Some of these issues are "trivial", but have to be considered seriously early on in developing FOMs and federations. The solution is probably to "consider early how to document and describe and discuss" but this is a fuzzy space. This is a good area for future investigation – to recommend a process for handling these issues ("process checklist").

The Task Group should evaluate current standards for applicability and should develop standards where appropriate for scenario development and distribution.

An XML schema based on CJTF non-real-time information should be explored by the FEDEP as a rapid means for distributing scenario implementations and updates. M&S and planning tools would implement and take advantage of the centrally managed database of exercise (and experimentation). CJTF operations ordering and tasking would ideally be the basis for the desired format extended to the FOM parameters. For example: unit positions could be rapidly updated, threat systems parameters changed, and defended asset lists modified.

The NATO ALTBMD Feasibility Study is a possible source of data, as is the NATO Missile Defence Feasibility Study.

5.4   OPERATIONAL INTEROPERABILITY

5.4.1   Lack of Standard Procedures and Methodology for EAD

M&S is able to provide a test bed for developing and examining the validity and utility of tactics, techniques, procedures, concepts of operation, and planning for EAD.

The M&S terminology is dependent on the terminology of the domain of consideration (in this case EAD). Use of common terminology, definitions, and terms of reference to avoid confusion and to allow exchange of information. We need to identify all relevant documents and sources of information in a common repository. We also need to identify the organisational structure and management of updates.

5.4.2   Cost and Limitations of Exercises

Field exercises will remain necessary. However, simulated (or partly simulated) exercises are able to provide cost-effective alternatives in areas where the goals are achievable within a (partially) simulated environment or as preparation for a field exercise.

5.5   CONCLUSION

Based on these considerations, the Task Group recommends development and demonstrations of NATO and national test bed interoperability. As a first step research into a common FOM, procedures and data sets is required. Following these activities the development of the test bed can be undertaken. Chapter 6 addresses this in more detail.

Chapter 6 – M&S INFRASTRUCTURE TO VALIDATE EAD C2 INTEROPERABILITY

6.1   INTRODUCTION

The objective of this chapter is to define an M&S infrastructure in order to validate EAD C2 interoperability:

- Interconnectivity (Technical interoperability)

- Consistent processing (System interoperability)

- Coherent doctrine and procedures (Operational interoperability)

The triple validation should be developed in this order (See Figure 6.1-4):

- For technical interoperability validation purposes, NATO/Nations EAD C2 models are required for analysis and testing of the EAD tactical Commands functions and the exchanges of the operational messages and the Tactical Data Link.

  - Simulation of the subordinate tactical control, fighters, GBAD, sensors and threat is also required to provide a EAD environment. This EAD environment must be consistent over the nations providing this simulation.

  - Operational directives as provided by higher commands and the operational EAD situation reported by tactical commands required some tools, but not necessarily a simulation.

- For system interoperability validation purposes, integration of real NATO/Nation tactical commands (i.e. CAOC, ARS, etc.) and utilisation of real communication for simulations in interfaces will be necessary.

  - The simulation of EAD environment provided for system interoperability validation should be identical for technical interoperability validation.

  - Validation of technical interoperability with operational level cannot be achieved as long as NATO ACCS development for JFAC is not achieved. Interim tools and prototypes should replace real Operational C2.

- For operational interoperability validation purposes, Computer Assisted eXercise (CAX) will be used.

  - The simulation of EAD environment provided for system interoperability validation should support the scenario of the exercise.

  - JFAC, LCC and MCC should be the training audience. The Response Cells (CAOC for JFAC, AOCCs for LCC and MCC) should use real EAD C2 tools for validation purposes.

To support this triple validation a single HLA federation based on NATO/National voluntary contribution could be set up in a following demonstration phase to this current study.

The remaining tasks are to define the possible federation architecture, the NATO/National contributions and the road map.
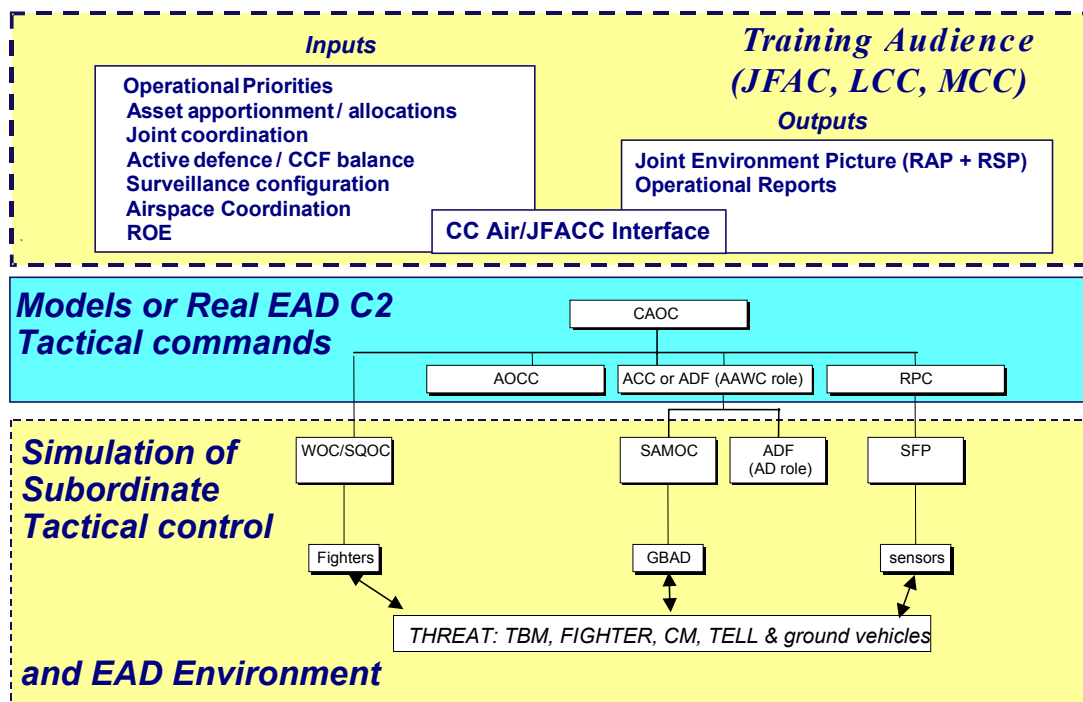
Figure 6.1-1: M&S Vision for EAD C2 Interoperability.

6.2   PRIORITIES AND M&S VISION

The M&S infrastructure priority considered will be in a NATO/**Multi-national co-operation perspective**. Special point of interest is the case of NATO operational commands augmented by National Deployed CAOC on external theatre.

The demonstration should be based on a 3-level architecture:

- Operational Level (non-simulated). Real CCIS and operational staff will be able to interact with the tactical commands level. This level could be a training audience for exercise training or experimentation in order to support operational validation.

- Tactical Command Level (Simulated or real C2). The C2 of the tactical level commands is the main target for the system validation and ACCS/LOC1 should be used as model of reference for legacy EAD functions.

- Tactical Control Level (Simulated). This simulation will support validation of technical interoperability with tactical command level.

6.3   M&S INFRASTRUCTURE REQUIREMENTS[1]

The overall objective of the EAD C2 Interoperability Testbed is to create an environment for addressing missile defence interoperability issues in the near-term. The environment should address interoperability up front and independent of any particular exercise or experiment so that our analysts can focus on the primary problems of:

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[1] The text of the opening paragraphs of this chapter were written in cooperation with the authors of the paper "A Multi-National, Distributed testbed for Extended Air Defence BMC3I: Past Experiences & Vision for the Future". Presented at NATO Modelling and Simulation Conference 2003, Antalya, Turkey [Ref 9].

- Verification and validation of NATO's command and control concepts of operations for missile defence.

- Identification and evaluation of missile defence C2 system requirements.

- Test and evaluation of missile defence prototype software.

- User-in-the-loop concept evaluation.

The testbed should provide an environment that allows us to perform these functions without creating an unduly large burden on its users. In other words, the testbed should support the research objectives, and not become an objective in and of itself.

The vision of a useful testbed is more than just a collection of models that can exchange information with one another. It includes the following dimensions:

- Facility related infrastructure.

- Hardware related items.

- Core simulations and models.

- Prototype software.

- Distributed simulation capability and support infrastructure.

- Analysis tools.

- NATO reference databases.

Each of these areas will be addressed in more detail in the following sections.

6.3.1 Facility Related Infrastructure

The facilities supporting the testbed should be able to handle NATO security levels up to and including NATO Secret. It must allow repeated access to military and technical representatives from NATO member countries and their equipment, and have the necessary NATO network connections to allow remote participation in NATO experiments and exercises. Adequate support staff should be available.

6.3.2 Hardware Related Items

The testbed should have a robust hardware suite available to it. This hardware suite must support prototype and model hosting, a centralised server capability, sufficient storage and network capacity, as well as a well-documented and tested backup system.

6.3.3 Core and Prototype Simulations/Models

The interoperability testbed can be thought of containing two broad categories of simulations. The first category can be described as "core" tools that model theatre level interactions and effects. This set is a relatively small suite of models that must cover a range of capabilities and functions. These models must support studies and analysis, prototype development, and exercise/experimentation objectives. In addition, they must be able to exchange information with each other either by common data structures in support of analysis efforts or by distributed simulation techniques such as HLA (High Level Architecture) or DIS (Distributed Interactive System) in support of experimentation.

The second category can be described as weapon, sensor, and C2 system emulators. These will vary from experiment to experiment and will often be supplied and supported by technical experts from NATO member nations. This set also includes actual weapon and sensor system hardware. In general, these system will be available for a short time to support the specific exercise or experiment, and will then be removed.

Typically, the second category will consists of a mix of existing models/tools (in many cases without access to source code) and 'prototype' software that is following a spiral development process.

6.3.4 Distributed Simulation Capability

A distributed simulation capability is a prerequisite for the interoperability testbed. The testbed must allow for the inclusion of legacy systems still using DIS, but should be based upon HLA and take advantage of the benefits it provides. A FOM that is specific to the needs of the missile defence mission area should be defined, and the core models should be made to conform to it. A customised FEDEP (Federation Development and Execution Process) should be developed for the interoperability testbed taking into account its core capabilities and reoccurring elements and processes.

One particularly important aspect of this distributed simulation capability is the way in which tactical data links (TDLs) are represented and accessed.

Finally, in-house HLA expertise and a set of network/HLA diagnostic tools are necessary, as debugging and analysing distributed experiments can be extremely difficult and time consuming.

6.3.5 Analysis Tools

A common set of tools designed for distributed experiment analysis is necessary to quickly and effectively collect, reduce, and display the results of an experiment. This is particularly important for experiments and exercises where a large number of people are involved. As distributed experiments tend to generate large volumes of data spread across multiple computers, this can also be a very challenging task. The chief objective here is to allow people to spend their time addressing, analysing, and discussing the experiment results, not waiting for the results to be collected and displayed. The ability to quickly and succinctly generate "After Action Reports" would also be extremely useful.

6.3.6 NATO Reference Database

The final dimension that makes up our vision of an EAD C2 interoperability testbed is access to a well-defined and sanctioned set of NATO reference databases. These databases include environment models (e.g. terrain) as well as threat representations, weapon/sensor system models, and standard scenarios blessed by the NATO military staff. These databases must be accessible, controlled, and maintained. The objective is to have the desired data, ready to go, with no development or set-up time required.

6.4 DEMONSTRATION CONSTRAINTS

This report makes a number of recommendations for the way forward. However, in order to provide credence to these recommendations it is proposed that some element of practical demonstration should be part of the next step.

However, such a demonstration will be constrained in a number of ways:

- The reference scenario and the demonstration will be constrained by the NATO/National contributions.

- The NATO/National contributions must contain as a minimum:
  - NATO ACCS/JFAC Interim Operational Tools
  - Models of National and/or NATO Tactical command including CAOC, AOCC, ACC/ADF and RPC (several nations contributions are possible)
  - Simulation of EAD environment (several nations contributions are possible)

- Operational message and Tactical Data Link simulation-C2 interface is a driver for the federation design.

    - The simulation of the EAD environment does not require high fidelity models, as long as the operational message and Tactical Data Link information are provided.

    - If several simulations of the EAD environment are used these simulations must be consistent.

- A compromise must be found between a platform level granularity and a suitable granularity for operational exercises (scenario with large number of platforms). Examples:

    - Land tracks are at platform level.

    - For sensors, only the information generated by the Sensor Fusion Post has to be provided to RPC models (not the raw data as provided by the sensors).

    - Response Cells cannot manage land units at the platform levels (too many platforms).

    - TEL hunting scenario should be managed at platform level.

6.5 PRELIMINARY FEDERATION DESIGN

6.5.1 Voluntary NATO/National Federate Contributions and Possible Functionality Allocation

Possible NATO/Nations model contributions to the federation are shown in the following table:

Table 6.5-1: Possible NATO/Nations Model Contributions

Component Type	Real-World Component	Model	Host
Command and Control	DCAOC	POSEIDON (Stradivarius-Saxophone)	FR
	ACC	LSID, EADTB & POSEIDON	NC3A & FR
	RPC		
	SFP		
Weapon Systems	GBAD & SBAD	J-ROADS, EADSIM	NL
	GBAD	POSEIDON	FR
	GBAD & SBAD	EADSIM	US
Sensors	Early Warning	SEW	NC3A
		EADTB	
		J-ROADS, EADSIM	NL
	NAEW & UK E3-D	EADTB	NC3A
		ACSTB	UK
	GBR	EADSIM	US
		POSEIDON	FR
Threats	BMs	EADTB	
		EADSIM	
	CMs	ACSTB	UK
	UAVs		
	Manned Aircraft		
Ground effects	BC effects	PEGEM	US
		HAPPIE/RIOT	NL

6.5.2   Possible Functionality Allocation

An anticipated functional federation architecture is proposed in figure 6.5-1. In this figure, federates are split by model functionality and several federates could be used for the same functionality in order to cover the variety of national weapons or sensors than could contribute to a NATO EAD system. The number of federates can be reduced by grouping several functions into the same federate.

The following federate functions are identified:

- DCAOC federate. This federate should be used as Response cell for training audience (JFAC level) and should support non real time interoperability with operative level. Provision for scenario generation toward other federates is to be considered.

- SEW C2 federate. This federate should support Early Warning Surveillance C2 functions. This federate will interact with sensor federates through data link and will initiate an EAD Recognised Air Picture (RAP) spread on the Theatre of operation.

- EAD ARS C2 federate. This federate should model the subordinate tactical command C2 to the DCAOC: ACC, RPC and subordinated SFP. The RPC will contribute to the EAD RAP within the DCAOC Area Of Responsibility from the tracks handled by the SFP. The ACC will co-ordinate the weapon allocation through the SAMOC. The SFP model will interact with sensor federates through data link.

- Simulation interface to Hardware In the Loop (HWIL). This interface will provide the capability of linking the HLA federation to the real C2 systems through a Real Link-16 Network and/or through a specific interface (especially for simulated threat).

- SAMOC & Weapon Systems federates. These federates should model subordinate SAMOC to the ACC and Air Defence Weapons systems subordinates. Various national weapon systems should be represented.

- Sensor federates. These federates should model the sensor subordinate to the SEW C2 and the sensors subordinated to the SFPs. Various national sensors should be represented.

- Threat federates. These federates should model the various threats.

A consistent HLA – Data link Interface layer should support real-time interoperability between federates and simulation – real C2 data Link interfaces.
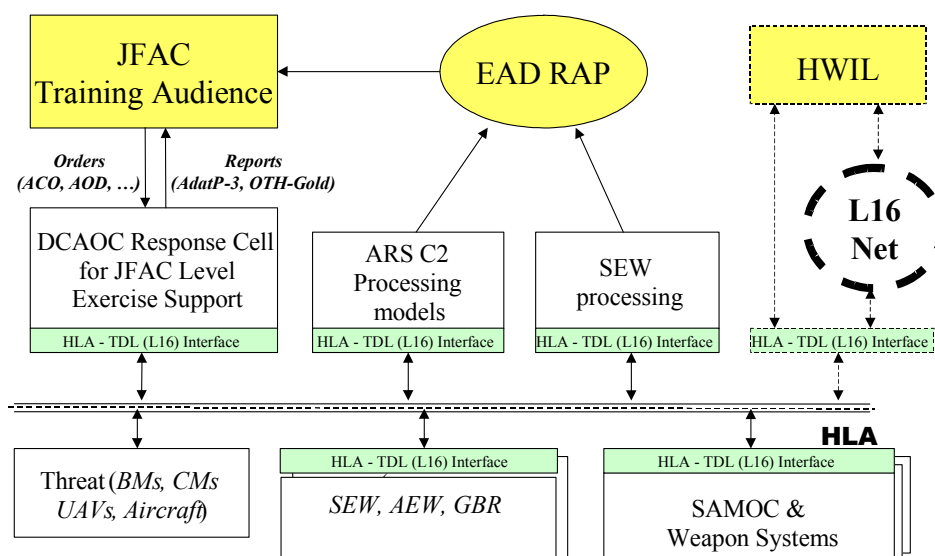

Figure 6.5-1: Functional Federation Architecture.

6.5.3 Development Plan

An EAD exercise is the ultimate goal to assess the EAD C2 interoperability. Before starting this exercise the capability to set up the simulation has to be demonstrated.

Three phases are proposed for M&S improvements in support of EAD C2 interoperability:

- Phase 0 (Y2003/04): Feasibility study (end of the current study). Tasks performed are the FEDEP steps 1 to 3 (define federation objectives, develop federation conceptual model, design federation). The remaining tasks include the following items:
  - Letters of Intention of M&S national contribution for the simulation demonstrator and following EAD CAX application (i.e. Simulations, operational or tactical command prototype, demonstrator or CAX operational specification, management support, etc.).
  - Multinational simulation infrastructure definition (sites, networks, simulation management, federation architecture, …).
  - Funding issues: NATO and Nations.

- Phase 1 (Y2004/05): Multinational simulation demonstration of EAD C2 system interoperability. The FEDEP steps 4 to 6 (develop federation, integrate and test federation, execute federation and prepare results) will support the multinational simulation development process.

  0) Supporting Studies:
      a) Identify suitable exercise
      b) Reference scenario to use for simulation demonstration
      c) Various items from Chapter 5 (e.g. TDL, XML, etc.)
      d) Federation and FOM design

  1) Federation Increment 1:
      Increment 1 will be designed to test the federation infrastructures.

  2) Federation Increment 2:
      This will implement the complete federation to perform the demonstration or exercise defined.

- Phase 2 (Y2006 and after): EAD C2 CAX application.
  - Customize the multinational EAD C2 simulation demonstrator for NATO exercises (Candidate exercises: Cannon Cloud, Dynamic mix, JPOW).
  - Updates of the federation and tools as required.

Chapter 7 – CONCLUSIONS AND RECOMMENDATIONS

One of the most important issues that must be addressed w.r.t. EAD within NATO will be **interoperability** between all TBM defense architecture elements within NATO: especially the **Command and Control elements**; tactical and procedural co-ordination between combined and joint EAD forces; and deployment and contribution of future elements (for instance airborne laser). NATO and the Nations can do something to improve Command & Control and "**turn individual weapon systems (point solutions) into a defense system**". An effective way of knowing what Nations should do is to try it through simulation (and if clever progressively work to a situation where the simulated elements are replaced by real ones). This simulation environment could also provide a training framework.

This report out of the MSG006/TG006 Task Group describes the issues relating to EAD C2 interoperability within NATO, the current use of M&S to support the EAD field (e.g. training, research and analysis) and it identifies opportunities for improved support through M&S. The TG concludes that with respect to EAD, the weapon systems are likely, as usual, to do what they do. Nations and NATO can get the best value for money through the Command & Control and co-ordinate the weapons, provide warnings for passive defense, cue sensors, etc.

The findings of the study include the fact that although HLA is the accepted standard for M&S interoperability, many existing models and simulations can not effectively interoperate due to lack of compliancy either to HLA or to a standardised datamodel (i.e. FOM). The TG identified the need for standard FOMs that cover tactical datalinks (TDLs) and recommends the TDL FOMs currently under development within the Simulation Interoperability Standards Organisation (SISO). The TG recommends that a tailored version of the FEDEP is developed. This FEDEP should also include the federation agreements as derived from best practice experience.

One of the conclusions coming out of NATO's Active Layered Theatre Ballistic Missile Defence Feasibility Study (ALTBMD FS) is the need for a Testbed to reduce the schedule risks associated with the integration of a variety of weapon, sensors, and BMC3 systems. The extension phase of the ALTBMD project was tasked to define the requirements for the TBD Interoperability Testbed. These results are due by the end of 2003. The MSG006/TG006 proposes to set up a follow-on programme to demonstrate the possibilities of M&S to C2 interoperability in the EAD area. The MSG006/TG006 follow-on programme will merge its recommendations with the requirements as defined by ALTBMD. This programme will demonstrate solutions to the problems identified (e.g. a reference FOM). This activity will primarily take place in 2004/2006 and will depend on the selection of suitable national programmes that can serve as a framework.

By establishing a distributed testbed capability, integration and interoperability issues can be identified and resolved well in advance of system fielding. Activities and results of the follow-on MSG006 activities should be linked up and harmonized with the ALTBMD programme of the CNAD/Missile Defence Project Group.

The MSG006/TG006 will prepare a SOW/TOR document to propose the described follow-on project.

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Appendix B – MODELS AND SIMULATIONS

B.1 ACSTB

The Air Command Systems Test Bed (ACSTB) is a QinetiQ simulation and modelling facility which is used to provide expert advice and informed consultancy on interoperability and integration issues associated with the procurement of C3I systems. ACSTB modelling focuses on the exchange of situation awareness data among platforms via Link 16 and is used to assess and develop the designs of the data handling systems that fuse data link track data with on-board sensor data for a variety of platforms.

The ACTB modelling suite contains high fidelity representations of the sensor detection, tracking, track correlation and fusion processes for a variety of platforms, as well as a detailed representation of MIDS/JTIDS communications. The platform models are used to undertake detailed assessments of the likely performance of the on-board C3I systems in a range of simulated scenarios, with a focus on the operational utility of the tactical pictures that are produced.

Typically, the ACSTB is used to assess issues that are too complex for standard paper-based analysis. The modelling environment is particularly useful in that it can represent environments that cannot easily be reproduced in live trials or exercises.

The ACSTB contains detailed models of the C3I capabilities for Eurofighter, E-3D, Sea Harrier, Sea King Mk7, and Type 42 destroyer. The ACSTB makes use of the Total System Model (TSM), QinetiQ's Air C3I modelling toolkit, including its sensor & data link communications models and scenario development tools, together with its own comprehensive display, logging and analysis facilities. The TSM sub-system sensor and communications models that have been developed for the ACSTB include: Surveillance radar, Airborne Intercept radar, Non Co-operative Target Recognition radar mode, IFF, Forward-looking infra-red, ESM, Extended Kalman filter tracker, and a JTIDS/Link 16 communications model.

The platforms represented within the ACSTB are at different points in their respective JTIDS/MIDS integration lifecycles, but the representations are based on the most detailed specification information available. In some cases the platform models are based on requirements specifications; in others they are based on contractor design specifications and performance trials analysis; while in the case of the E-3D, the model is validated by comparison with the real system software code. For the Sea Harrier, the model was developed to prove the practicality of the system specification for the Sea Harrier's on-board fusion processes, which was co-written by BAE Systems and QinetiQ.

The ACSTB models are used to support the UK MOD Integrated Project Teams (IPT) in their assessments of the proposed designs for new C3I systems being procured. For example, the Eurofighter IPT is using the outputs of the ACSTB's Eurofighter Sensor Fusion modelling programme to:

- Understand more about UK Government Furnished Information data liability;
- Gain an insight into the Eurofighter Sensor Fusion process;
- Determine the potential for improving the Sensor Fusion design;
- Support investigations into the ability of EF to fuse sensor and MIDS data to form a tactical air picture;
- Ensure clarification and correction of the design specification;
- Help harmonise of the sub-system interfaces; and
- Feedback modelling results to the contractor to help them improve the design.

The ACSTB platform models represent current or anticipated initial in-service designs, as such they are capable of acting as baseline capabilities and being used to assess options for sub-system development.

Most recently the E-3D model has been used to assess the potential of the Lockheed Martin 'Best of Breed' tracker (BBT), while the Eurofighter model is being used to look at the use of distributed, measurement fusion tracking using MBDA's Integrated Air Tracking Package.

In both cases the trackers have been integrated as black boxes and fed realistic simulated data; the tracks produced by the trackers were fed back into the platform models for subsequent processing and analysis. For the BBT assessment, in addition to simulated data, recorded E-3D radar trials data sets were processed and fed into the test and baseline trackers for comparison.

B.2 BRAWLER

BRAWLER is the US Air Force's principal resource for in-depth analysis of the interactions between aircraft performance, air-to-air weapons lethality, tactical procedures and pilot behaviour. A mainstay of USAF analysis of fighter and air-to-air weapon acquisition programs for more than two decades, BRAWLER has continually evolved to provide insights into the doctrinal and technological changes necessary to transform the Air Force from its counter-Soviet posture in Central Europe to the Global Engagement capability so recently evident in campaigns over Serbia and Afghanistan. (http://www.l3com-analytics.com/brawler.html)

B.3 C4ISRMOS

C4ISRMOS (C4ISR Modelling and Simulation) is a Turkish tool that is still under development. This model is not scheduled for operational service until 2006.

B.4 CAMDEN

The Co-operative Air and Missile Defence Exercise Network (CAMDEN) was tested successfully in the Roving Sands exercise at Ft. Bliss and first used in JPOW in 1998.

CAMDEN integrates live, virtual and constructive simulations using distributed simulation techniques (LAN and WAN) to create a synthetic air and missile defence battlefield. CAMDEN operates by stimulating weapon, sensor and C2 systems at the unit level, enabling normal tactical stimulation of the C2 hierarchy within which the systems operate. This enables assessment of interoperability at any level within the C2 hierarchy (weapon to weapon, C2 to weapon, C2 to C2). Currently CAMDEN includes ground, air and sea-based air and missile defence systems; attack operations systems and passive defence systems; tactical missiles and aircraft; instrumentation for live systems; and control, monitoring and analysis systems for simulation management and debriefing.

Source: 'JPOW – Exercising Missile Defense Operations', Article in MST issue 3, 2002

B.5 EADSIM

The Extended Air Defence Simulation (EADSIM) is theatre-level simulation of air, missile, and space warfare. EADSIM is a medium fidelity tool capable of modelling systems and their associated C2 decision processes and communications. EADSIM is owned by the U.S. Army SMDC and is developed by Teledyne Brown Engineering. EADSIM is a community accepted tool used extensively for analysis,

as well as, exercises, training and operations planning by over 300 users across all services. Examples of the possibilities are:

- TMD active defence studies involving BMC3I architectures, satellite early warning and naval based sensors.

- Threat modelling to include BMs, cruise missiles, aircraft, etc. (scripted, autonomous or commanded).

- Passive defence measures to include EMCON.

- Conventional Counter Force.

- HLA and DIS compliant interfaces available and under development.

Web Sites: www.eadsim.com and
http://afmsrr.afams.af.mil/bookmark_link.cfm?RID=MDL_AF_1000008

B.6   EADTB

EADTB is described by Raytheon as a multi-purpose, event-driven simulation and modelling tool kit with emphasis on user control and flexibility, designed for battle-space modelling of land, sea, space, and airborne assets. It provides analysis capability from subsystem through system-level world-wide system interoperability, including communication for Battle Management Command, Control, Communications, Computer and Intelligence (BMC4I) applications. EADTB is an object-based model that provides multiple levels of aggregation within a single scenario providing emphasis in the areas of interest.

TRW is the subcontractor who designed and built the EADTB software suite. TRW describes EADTB as an analytic simulation for examining theatre air and missile defence issues in a family of systems context. With EADTB, users set up an analysis or experiment by placing specific system elements on a gameboard and writing the rule sets that govern their interactions.

EADTB is the backbone of a testbed for high fidelity simulations of theatre Battle Management, Command, Control and Communications (BMC3). The product is fielded in over 30 CONUS and OCONUS sites. The TRW company has participated in studies for theatre missile defence and for joint and coalition applications for NATO and other potential users.

Reference TRW site:
http://www.trw.com/marketplace/main/0,1151,39_1541_135_4224_212^5^212^212,FF.html

B.7   ESAMS

Enhanced Surface-to-Air Missile Simulation (ESAMS) focus is analysis of a single airborne target vs. SAM. ESAMS was developed by AFSAA in the late 1970's as TAC Zinger and renamed ESAMS in the early 1980's. ECM functionality was added in the late 1980's. SA-8 models were verified and validated 1991-1995 by the Naval Air Warfare Centre in China Lake. ESAMS models the interaction between a single airborne target and a surface to air missile (SAM). It provides a one-on-one framework in which to evaluate air vehicle survivability and tactics optimisation. Detailed data has been abstracted from intelligence information and incorporated into the model to provide comprehensive representation of the Soviet SA-2 through SA-15 land-based missile systems and the SA-N-1, SA-N-3, SA-N-4, SA-N-6, SA-N-7, and SA-N-9 naval systems. Though the primary model result is probability of kill, the ESAMS user can examine details of other aspects of the engagement such as the missile flight path, guidance characteristics, and the effects of electronic countermeasures and terrain. ESAMS will be converted to JMASS. Efforts are on going to store PK data algorithms to reduce volumes for individual studies & models in MASTR.

Reference Web Site: http://www.afsaa.hq.af.mil/SAA/MODELS/esams.html and
http://afmsrr.afams.af.mil/bookmark_link.cfm?RID=SMN_AF_1000041

B.8   JMASS

JMASS (Joint Modelling and Simulation System) is the DoD engineering-level architecture for modelling and simulations.

What gets delivered on the JMASS CD is an **architecture and associated tool set**, which supports the building of models, the combination of models into a simulation, the execution of simulations, and the post-processing (i.e. examination) of the results (i.e. output data) of executions of simulations. No models or simulations, other than very simple tutorial examples, are delivered on the distribution CD, i.e. you cannot usefully "run" anything on the CD. No analysis of any sort is possible using just the JMASS software as it comes on the delivery CD.

The JMASS program supports simulation-based acquisition programs by providing a flexible simulation infrastructure that assists engineers and analysts in the application of digital models to real world applications. JMASS supports varying degrees of model fidelity: from analytic models, with their relatively high degree of abstraction, to highly imitative models that mimic, in great detail, real-world systems. JMASS is capable of supporting real-time flyouts, including those used in test and evaluation (T&E), and slower-than-real-time models capable of predictive ECM analysis. JMASS is becoming the standard simulation for all phases of the acquisition lifecycle.

Dynetics is the developer of the JMASS architecture, the standard framework for engineering- and engagement-level models. Intelligence agencies provide JMASS models of threat systems that are becoming the validated reference for threat performance. JMASS provides a plug-and-play framework for models, and supports using the same models in conditions ranging from constructive simulations up through hardware-in-the-loop (HITL or HIL) testing. Current JMASS efforts include electronic warfare and electronic combat (EW/EC) analysis, HITL, Post-Mission Miss Distance Scoring, and real-time training applications. JMASS is currently being used for radar analysis and will soon include support for electro-optic and infrared (EO/IR) analysis. JMASS is installed at over 300 user sites and is being used at several T&E locations.

JMASS 5.0, retains all capabilities of JMASS98, and includes as several important enhancements including the ability to interoperate with other simulations using the High Level Architecture (HLA) protocol.

JMASS features:

- Software structural model for reuse
- Model application programming interface
- Simulation engine
- Visual development tools
- Analysis tools
- Commercial off-the-shelf and legacy tool interface
- Local model and data library
- Resource repository

The Modelling and Simulation Training (MASTR) is a support tool for modelling and simulation that can be used with JWARS, JMASS, JQUAD or any other simulation system. MASTR can help analysts create

scenarios of warfare against potential enemy threats, while also providing these analysts with a study management system that allows them to track and document the data used during the course of the study.

MASTR allows analysts to maintain a detailed diary of day-to-day data and study assumptions and intermediate analysis. The tool enables analysts to document changes made to input and data files and allows analysts to document and verify data integrity, which can help analysts decide to accept or reject study conclusions
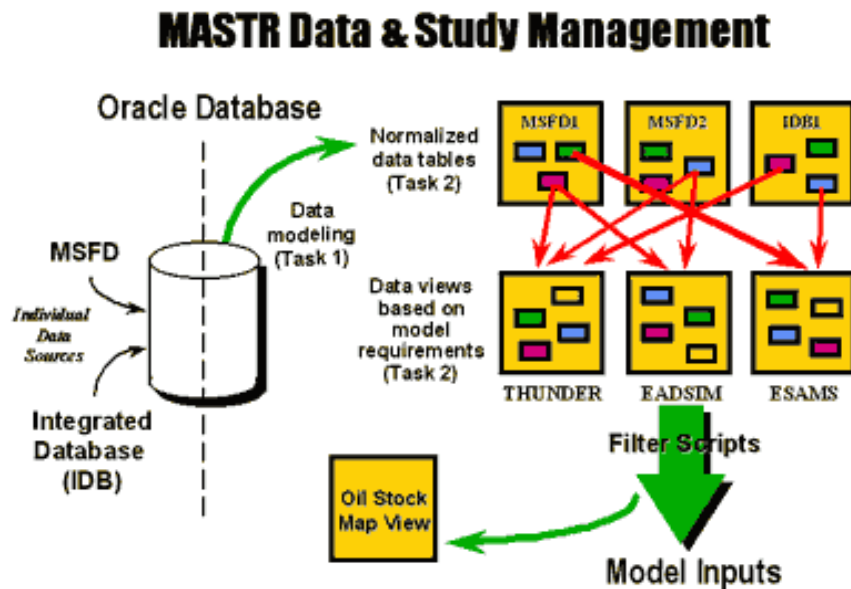
Figure B-2: MASTR.

Web references:

http://www.dynetics.com/solutions/modeling/jmass.htm

http://www.caci.com/Products/simulation/jmass.shtml

http://www.caci.com/Products/simulation/mastr.shtml

B.9 J-ROADS

The Joint Research on Air Defence Simulation (J-ROADS) model is an interactive computer-assisted simulation that models the entire Extended Air Defence domain. Based on SEAROADS (used in the NATO Modelling and Simulation Team), J-ROADS is developed especially for the RNLAF, RNLN, and RNLA especially for support in air defence exercises (like JPOW). It has a Human in the Loop capability and currently has DIS and Link-16 interfaces. An HLA interface is planned for the near future.

B.10 JTLS

The Joint Theatre Level Simulation (JTLS) is an interactive, computer-assisted simulation that models multi-sided air, ground, and naval combat, with logistical, Special Operation Force (SOF), and intelligence support. JTLS was designed as a tool for use in the development and analysis of joint and combined (coalition) operation plans, but is frequently used as a training support model. JTLS started development

in 1983 as a project funded by the U.S. Readiness Command, U. S. Army Concepts Analysis Agency, and the U. S. Army War College. It has had continuous functional and system upgrades since that time. The JTLS Program is managed by United States Joint Forces Command Joint Warfighting Centre Suffolk.

The JTLS system consists of six major programs and numerous smaller support programs that work together to prepare the scenario, run the game, and analyse the results. Designed as a tool for use in the development and analysis of operation plans, the model is theatre-independent and is now primarily a tool for driving computer assisted training exercises. The JTLS system operates on a single computer or on multiple computers, either at a single or at multiple distributed sites. Model features include Lanchester attrition algorithms, detailed logistic modelling, and explicit air, ground, and naval force movement. In addition to the model itself, the JTLS system includes software designed to aid in scenario database preparation and verification; entering game orders; and obtaining scenario situational information from graphical map displays, messages, and status boards.
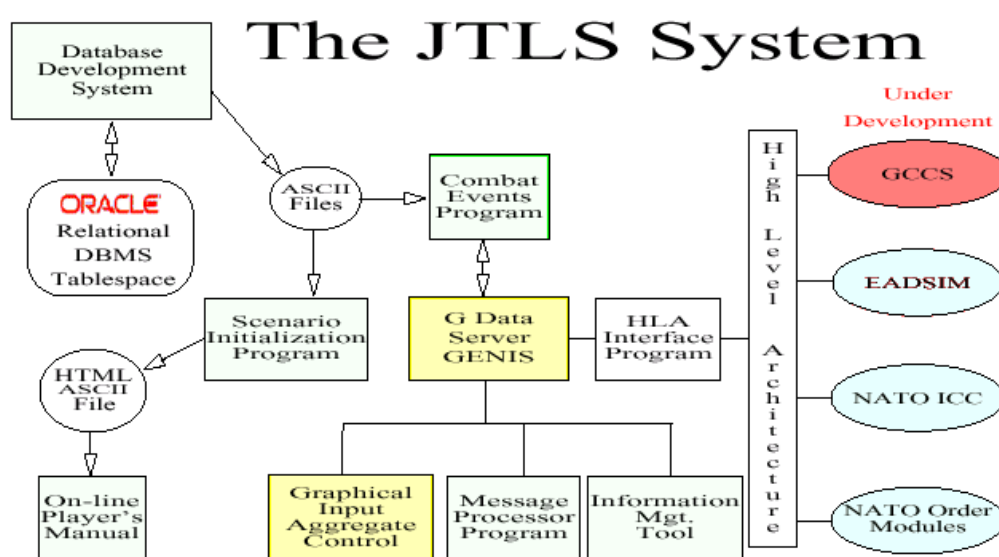

Figure B-1: EAD CAX.

Reference web site http://www.jtasc.acom.mil/pfp/jw500/jtls/

Note: JTLS has scenario tools and HLA interfaces are available or under development (e.g. to EADSIM).

B.11   MOSAIC

Modelling System for Advanced Investigation of Countermeasures (MOSAIC) is capable of simulating laboratory experiments, field tests, and live fire engagements between infrared (IR) missiles and aircraft with countermeasures. The system provides an automated method for performing sensitivity analyses and parametric optimisation of expendable parameters. A Windows-like interface allows selection of missiles, aircraft, and infrared countermeasures concepts of interest and scenario definition. MOSAIC is supported by an extensive database that includes missile seeker models, aircraft signatures, current flares, advanced flares, and platform flare dispenser locations.

B.12   NETWARS

The Networks and Warfare Simulation (NETWARS) Model was initiated as an effort to develop a high-fidelity communications modelling tool to be able to credibly model tactical communications demands

with all the stresses and inefficiencies that combat places on communication systems. The NETWARS project is a joint effort between all of the services, the Joint Staff (J-6), and many commercial companies. The basis of the tool consists of a front-end specifically built for the NETWARS project, which interfaces with the OPNET modelling environment and pulls data from a database that consists of Information Exchange Requirements (IER) data pulled from each of the services.

Web Site: www.disa.mil/D8/netwars and http://www.ga.erg.sri.com/netwars/index.html

NETWARS C4ISR Communications FOM. The Navy Modelling and Simulation Management Office (NMSMO) has invested in the development of standards for communication system models. The below report presents the reference attribute templates and standards in the form of a communication systems Reference Federation Object Model (FOM)

Technical Paper: C4ISR Communication Federation Object Model (NETWARS),
http://www.sisostds.org/doclib/obtain_doc.cfm?record_id=REF_1001405

B.13   PEELS

PEELS is a physics-based, fast-running terminal endgame computer simulation that predicts body-to-body (BTB), blast fragmentation warhead, and aligned-rod impact lethality resulting from interceptors engaging ballistic missile threats. PEELS predicts and/or analyses lethality specifically for a first impact event. By using established lethality criteria developed for a number of threats, PEELS predicts the probability of kill (Pk) given a hit as well as the submunition kill fraction (how much of the payload is defeated). These results can then be fed into a hazard prediction model to determine the ground effects caused by the residual (i.e. surviving) payload.

B.14   PEGASUS

Pegasus is a federation of simulations co-sponsored by DMSO and USJFCOM. This federation provides a toolset for assessing key issues facing the future systems planning and assessment. The Pegasus federation was originally developed in 1998 as a "trail blazer" effort intended to provide the DMSO with lessons learned concerning the use of the Federation Development and Execution Process FEDEP in support of analytical objectives. The original federation, consisting of the Army's ground combat model Eagle, the Navy's Naval Simulation System (NSS) and a variant of the Army's Extended Air Defence Simulation (EADSIM), proved highly successful in providing lessons learned and feedback.

Technical Paper: 00S-SIW-025, Optimising Performance of an Analysis Federation

B.15   POSEÏDON

POSEIDON is a simulation platform, used by the CASPOA (Centre d'Analyse et de Simulation pour la Préparation aux Opérations Aériennes), for training the operators of the CAOC or of the CDC (Centres de Contrôle, Control Centres). That platform has also been used for test and validation of the new CDCs, in terms of capacity, load and robustness. Its models are shared by the simulations of the CDEVS (Centre de Définition, Expérimentation, Validation du SCCOA).

The platform takes into account the following activities : scenarios preparation (creation of land, sea and air pictures, definition of simulated entities (sensors, centres), definition of moving targets and of their trajectories, definition of the theatre of operations (ACO, …), creation of meteorological data (or definition of interface with real meteorological data)), entities modelling, MMI modelling, and data-links modelling.

The entities attached to the C3I functions are modelled by their detection, tracking, fusion, identification and classification functions, and by the data-links they use (L1, NATO L1, L11B, NATO L11B, L16, IJMS, L11A, LCLA, LICCT, LCAUTRA, ADEXP, ISARD, AWCIES, LHorizon). The operational procedures and Man Machine Interface of these entities are also modelled. This permits the representation of higher level functions, like Air Mission Control, Flight Data Processing, Fire Control, Fire Coordination and 3D Coordination.

The platform includes an aircraft model. This model simulates the navigation function, the IFF transponder, jamming and other electromagnetic emissions, detection, surveillance and resource management. The platform permits the control of aircraft individually or in patrols.

Finally, the platforms offers different tools for archival, supervision, analysis of actions, cartography, viewing. It comprise an integrated interface which permits the communication with real entities through tactical data-links (L1, L11, L16).

B.16 SAMMOS

SAMMOS (SAM Modelling and Simulation) is a Turkish tool that is still under development. This model is not scheduled for operational service until 2006.

B.17 SEAS

SEAS is a multi-mission quick reaction analysis tool used to quantify the military utility of future space systems and concepts. SEAS models sensors, communications systems, and military forces in such a way that large scale missions or campaign level simulations can be run in reasonable times. SEAS was used to run quick bounding analysis to focus efforts of campaign models at 'Schriever AFB 2001 Space Games'. The SEAS analysis team conducted a designed of experiment (DOE), using multiple linear regression, to identify what factors influenced Red and Blue Air Losses and Time Critical Targets Drawdown. The factors included Force Structure, Counterspace Activity, and Force Application. The Force Structure was set up as baseline or robust. The Counterspace Activity factor models the degree to which either Red or Blue has a time advantage in conducting an effective counterspace campaign. The final factor is Force Application, modelling the Blue conduct of CONUS-based force applications, with an emphasis on counter-counterspace role. The three factor levels are no CONUS-based force applications, air-breathing assets such as the B-2 bomber conducting force application from CONUS, and space assets conducting CONUS-based force application. The level-of-effort devoted by SMC not only supported the expected & conventional play with this scenario, but went beyond to show the unique value of SEAS in exploring more creative "out of the box" approaches by Blue. This study is of use to future deployed forces and forward, in theatre, based facilities.

B.18 SUPPRESSOR

Suppressor is a US Air Force, event-stepped, mission-level simulation widely used by government and industry as a powerful tool for operational concept evaluation and electronic combat analysis. It conducts Measure of Effectiveness (MOE) and Cost and Operational Effectiveness Analyses (COEA) in evaluating different weapon systems, sensor systems, tactics, or command procedures in composite missions against an integrated air defence. Suppressor allows users to define, at various levels of detail, the types of military systems to be modelled and the way those systems may interact. Suppressor simulates human behaviour, sensors (infrared, electro-optical, radar, and radar warning receiver), radios, jammers, movement systems, and weapon systems.

B.19 TAMARI

TAMARI – NC3A's Theatre-Level Model for Air Related Issues (TAMARI) model can be used to investigate the likely performance of NATO forces under a variety of circumstances. TAMARI is a key (campaign level) model used in the derivation of future aerospace force requirements. TAMARI simulates air battle campaigns and comprises a Scenario Generator (to set up the runs), the model itself and a post-processor that displays the model results graphically.

http://www.silicon-valley.co.uk/commercial/bespoke/nato_cs_v1.0.htm

B.20 THUNDER

Thunder is an analytical simulation of campaign-level joint military operations developed under the auspices of the Air Force Studies and Analyses Agency (AFSAA). The simulation was designed and built expressly to examine issues involving the utility and effectiveness of air and space power in a theatre-level context. Operational since 1986 and continually modified and maintained to address evolving analytical interests, THUNDER results provide insights to senior decision-makers across the acquisition, policy and operations communities. THUNDER is a stochastic, two-sided, constructive computer simulation of air, land, and naval air warfare. It integrates the planning and execution of air and ground combat and support operations and provides a traceable "thread" from individual system to campaign impact by employing explicit air, space, ground and naval weapons, platforms and entities and reflecting their contribution in terms of combat and support capabilities and effects.

THUNDER approaches mission-level detail in air and space power interactions, yet retains sufficient scope to explore the broad impact of joint operations throughout the course of a theatre campaign. The simulation can be run in two modes: analytical and wargame.

The analytical mode supports traditional studies examining issues related to the contribution of systems, capabilities, forces and employment concepts in the context of theatre-level operational outcomes.

The wargame mode supports the near-real time intervention of participants in seminar-type gaming activities, accommodating side and player moves to dynamically influence the outcome of the run. There are several ongoing efforts to include space representation in M&S. The THUNDER model version 6.7 developed and used by the Air force Studies and Analysis Agency (AFSAA), for example, now includes the representation of GPS, vital to the delivery of precision-guided munitions (PGM), as well as space-based systems that perform ISR.

Reference website: http://www.l3com-analytics.com/thunder.html

Appendix C – OPERATIONAL PROTOTYPES

C.1 INDIA

At TNO-FEL in the Netherlands, air defence studies are performed to support the armed forces during procurement, upgrade and deployment of air defence systems. Various tools and models have been developed by TNO-FEL for quantitative analysis relevant for those studies. One of those models is INDIA (the INtercept DIAgrams model), developed to support deployment analysis. INDIA is an interactive air defence planning tool that addresses the problem of intercept performance prediction. INDIA provides an objective assessment of air defence deployment in both a graphical (intercept diagram) and numerical (Measures Of Effectiveness) way.

INDIA is a model calculating and drawing different types of intercept diagrams based on digitised terrain databases. Those intercept diagrams show the intercept capability of the deployment graphically around the protected asset.

INDIA provides quantitative measurements of the defensive quality against air defence guidelines. By quantifying the degree in which the deployment achieves the aim of the guideline, it will be possible to rank the various deployment options with respect to six basic guidelines. Together with the intercept diagrams this should give the air defence planner enough information to make an objective deployment choice, depending on his air defence mission, which determines the relative importance of the guidelines for MOE.

At this moment INDIA is used for air defence studies. A feasibility study has been started addressing the need for an operational air defence deployment planning tool, like INDIA, for the Royal Netherlands Air Force and Army.

Web Site: http://www.tno.nl/india

C.2 LSID

Link16 SAMC2 Interoperability Demonstrator. LSID is an NC3A developed software prototype designed to evaluate requirements for missile defence engagement coordination and situation assessment. The primary goal of LSID is to verify the findings of simulation-based analysis in an operationally realistic environment and to capture operational requirements coming from users. LSID develops a situation assessment of the missile defence battle based on tactical data link messages it receives. This assessment attempts to maintain an accurate picture of the number of attacking missiles in the air, which assets are being attacked, the numbers and types of weapon & sensor systems available to the operator, what their current available inventory is, etc. This assessment is then used by a) the operator to help him understand the situation and b) the weapon selection rules to select a preferred shooter for each engagement. The chief output of the LSID is then a series of either "engage" and "cease fire" commands to subordinate units. The objective system will consist of real-world missile defence weapon systems being controlled via tactical data link messages with human-in-the-loop display capabilities.

C.3 PLATO

PLATO (Planning & Tasking Tool). PLATO is an NC3A developed software prototype that facilitates the integrated planning of employment of joint force capabilities from strategic down to execution levels to conduct mutually supporting Conventional Counterforce (CCF), Active Defence (ActD) and Passive Defence (PD) operations against tactical missile threats. Sponsored by SHAPE and SACT, PLATO will

evolve to cover the entire range of Extended Air Defence (EAD), with the initial focus being placed upon planning ActD and CCF TMD missions. Three major input streams can be identified: the Prioritised Defended Asset List (PDAL), the enemy Order of Battle (OrBat) (resulting from the Intelligence Preparation of the Battlefield (IPB) process), and finally, the available TBM capable defence systems. The purpose of this prototype is to assist in the development of requirements for extended air defence planning functions envisioned for the NATO ACCS and Bi-SC AIS systems, as well as assisting in the development of future concepts of operations (CONOPS) for missile defence.

Appendix D – HAZARD PREDICTION MODELS

Before the Gulf War, there was very little priority given to modelling chemical and biological warfare agent dispersion. As a result, these models were relatively unsophisticated in their capabilities. Since the Gulf War, increased interest and support has resulted in major improvements in their capabilities. The following hazard prediction models were available during the Gulf War although their capabilities were relatively limited.

Reference website: http://www.gulflink.osd.mil/aircampaign/aircampaign_tabc.htm

D.1   ANBACIS

ANBACIS, the Automated Nuclear, Biological, and Chemical Information System was developed to provide a realistic, real-time chemical and biological downwind hazard prediction capability. ANBACIS is a separate software program that resides on the same Common Hardware System (CHS II) platform that contains the Maneuver Control System (MCS) Baseline software. ANBACIS is invoked by NBC personnel in order to input various NBC reports into the database for processing; or to conduct risk analysis and vulnerability assessments. The MCS/P baseline will alert the ANBACIS operator when an NBC message is received. The operator must then start the ANBACIS program in order to process the NBC report. It will then convert the NBC Reports utilizing the correct weather information that has been previously received electronically from the staff weather officer. ANBACIS will take the basic wind report and create the Chemical Downwind Report in seconds.

http://www.totse.com/en/politics/us_military/anbacis.html

D.2   HAPPIE/RIOT

One of the pillars of the defence against chemical and biological weapons is the Warning and Reporting system. Within NATO, standardised messages and procedures are used so that military units and civilian authorities can be warned before any contamination reaches them.

The HAPPIE/RIOT software program, developed by TNO-PML in the Netherlands, helps operators (NBC specialists) to carry out these procedures very fast and more accurate that the manual procedures that have been used in the past. In addition to standardised procedures, it can also generate hazard area predictions for any remaining chemical or biological hazards after intercept by a TBM with a B/C warhead. HAPPIE/RIOT is compliant with NATO's ATP45(B) message formats, interoperable with NATO's standardised software NBC-Analysis and uses ADRG raster format and digital chart of the world vector format. Sophisticated dispersion models and statistics on weather prediction errors are used to quantitatively calculate risk levels and areas.

Web Site: http://www.pml.tno.nl/en/ts/hazard_area_prediction.html

D.3   MATHEW/ADPIC

MATHEW/ADPIC The Mass Consistent Wind Field (MATHEW) is a mass-consistent wind field model that provides three-dimensional winds to the Atmospheric Diffusion Particle in Cell (ADPIC) model. ADPIC provides graphical plots of the dispersion and deposition of the substances being evaluated.

D.4 NUSSE

The Non-Uniform Simple Surface Evaporation (NUSSE) model predicts the hazardous environment created by a single liquid- filled chemical warhead. It calculates the coverage (footprint) of the warhead's lethal area on the ground by following the transport and diffusion of the agent vapour cloud from release to impact with the ground. NUSSE-4 is the current version.

D.5 PEGEM

PEGEM is the Post-Engagement Ground Effects Model, a computer model that has been developed to integrate the `dirty battlefield factor' into synthetic battlefield environments under a US Army Space & Missile Defense Command (SMDC) sponsorship. PEGEM provides realistic assessment on what happens when a TBM or cruise missile carrying weapons of mass destruction releases its payload either on top of, nearby, or at high altitude over the battlefield (for instance as a result of a TMD intercept). The model is produced by Mevatec of Huntsville, Alabama, and has been developed with support from SMDC's Missile Defense and Space Technology Center; the US Space & Missile Defense Battle Lab; the TNO Prins Maurits Laboratory in the Netherlands; and the UK's Chemical and Biological Defence Establishment (CBDE) at Porton Down.

http://www.mevatec.com/pegem/

D.6 VLSTRACK

The Vapour Liquid Solid Tracking (VLSTRACK) model determines ground deposition, dosage, and concentration from a single chemical release. VLSTRACK simulates the transport and diffusion of a biological or chemical agent cloud, and periodically computes a rectangular grid of values of a user-selected output measure, such as deposition (milligrams per square meter), dosage (milligrams per cubic meter of air), or particle concentration, at a user-selected height. VLSTRACK is developed and maintained by the Naval Surface Warfare Center (NWSC). As of Fall 1999, VLSTRACK is in the process of being converted to GRIDGEN.

http://www.msiac.dmso.mil/wmd_documents/GRIDGEN.htm

Appendix E – EXERCISES

E.1 CANNON CLOUD 02/CONSTRUCTIVE OPTIC WINDMILL-01

In November 2002, the exercise Cannon Cloud 02 was held, mainly executed in Germany. The overall aim of Cannon Cloud 2002 (CC02) was to plan and conduct a campaign and major operations at the operational level in a combined/joint collective defence scenario (High Intensity Warfighting). The primary participants were JHQ CENT, HQ AIRNORTH, Corps and CAOCs.

With the Constructive Optic Windmill (COW) element, AIRNORTH, RNLAF and GAF brought Theatre Ballistic Missile Defence (TBMD) into CC-02 (mainly Army oriented) for the first time.

The COW-exercise objectives were for AIRNORTH to practice the execution, synchronisation and Command & Control of TMD Operations, and for the RNLAF to support HQ AIRNORTH TMD Exercise Objectives.

In COW, the Extended Air Defence Simulation Model (EADSIM version 10) was linked to the Joint Theatre Level Simulation model (JTLS version 2.4) via a High Level Architecture (HLA)-federation, operationally via a Run Time Infrastructure (RTI 1.3NGv4). JTLS was linked to the HLA federation via the JTLS HLA Interface Program (JHIP). The PACER program enabled time management between EADSIM and JTLS.

E.2 JPOW

Joint Project Optic Windmill VII (JPOW VII) is a Royal Netherlands Air Force sponsored and executed Combined and Joint Extended Air Defence / Theatre Air & Missile Defence Initiative, supported by US European Command (USEUCOM) (CINC Assessment Program), US-Missile Defence Agency (MDA) and German Air Force (GAF).

Joint Project Optic Windmill's initiative dates back to 1996, when the RNLAF together with USEUCOM and GAF successfully executed the first JPOW. Although planned as a one time event, it was quickly followed by its successors in 1997 (JPOW-2), 1998 (JPOW-3) and 1999 (JPOW-4). Throughout the entire series, its main objective was to demonstrate and exercise all pillars of Theatre Air and Missile Defense (Passive Defence, Active Defence, Counterforce / Attack Operations (Simulated Only)) and to develop and explore interoperability between all participants and refine the associated Tactics, Techniques and Procedures (TTP).

In 2002, the Royal Netherlands Air Force has conducted the seventh edition in the series of EAD/TMD exercises in September 2002 at the facilities of the Royal Netherlands Air Force Base "De Peel" in the Netherlands. JPOW-VII main emphasis was: Small Scale EAD/TAMD Tactical Level Exercise.

JPOW-VIII is scheduled for May 2004 on Crete, Greece, and will be an "Out Of Region" Initiative and will involve NATO Southern Regions Agencies (ACC AIRSOUTH and CAOC-6) as player/observer.

Web references: http://web.cas-inc.com/divs/jpow/
http://www.hqeadtf.giessen.army.mil/Exercises/jpow_v.htm

E.3 JWID

The Joint Warrior Interoperability Demonstration (JWID) is an annual warfighting demonstration hosted by a different branch of military service every two years. The project introduces off-the-shelf, new and

evolving technologies that solve command and control, communications, computer, intelligence, surveillance and reconnaissance interoperability issues for joint and combined war fighters. Expert teams identify potential investment strategies toward long-range solutions and facilitate short-term rapid insertion of low-cost, low risk leading-edge technology into the warfighter environment.

Web Site: www.jwid.js.mil

E.4 LUCKY SENTINEL

LUCKY SENTINEL is U.S. Army/U.S. Army Forces Central Command (ARCENT) premier battlestaff exercise. This exercise is conducted annually and is designed to train the Coalition/Joint Task Force-Kuwait staff, Kuwait Armed Forces staff, Kuwait Ministry of Interior staff and selected support unit staffs at operational level of warfighting. Lucky Sentinel is an ARCENT led OPLAN exercise in Kuwait, testing the JRSOI portion of the OPLAN. Lucky Sentinel includes air land and sea operations with emphasis on the joint targeting process and integration of all component air and fires capability. Also included is training on theatre missile defence operations and reception staging.

Lucky Sentinel 01 was a multi-national, joint CPX taking place in Kuwait and the USA from 24 March – 11 April 01. The exercise involved troops from the UK, US and Kuwait. More than 600 personnel poured into Camp Doha for the Lucky Sentinel 2001 exercise which tested the battle readiness of soldiers and systems from Headquarters, 3rd Army/Army Forces Central Command from Fort McPherson, Ga. LS is a computer-assisted, command-post exercise (CPX) that involved multi-national forces and joint service operations, including reserve forces. It is conducted to test the staff of the Combined Joint Task Force-Kuwait for wartime operations. It's a computer exercise run from Atlanta using elements in Kuwait. It helps get the bugs ironed out of operations. Soldiers reacted to simulations produced by the computer. The exercise play consisted of various scenarios from troop movements to air strikes and terrorist attacks. The staff had to co-ordinate logistics and keep the battle running as planned. A highly detailed terrain map, stretching more than 100 feet, gives a new perspective to how moving pieces would interact during battle; not only with each other but also with all the coalition forces within the theatre and various terrain features around Kuwait.

Third ARCENT employs a unique tool to improve coalition interoperability during exercises and contingencies in theatre. In addition to direct staff-to-staff co-ordination and traditional liaison officers, ARCENT also plans to use an ad hoc co-ordinating staff. This staff would consist of coalition and joint personnel dedicated to ensuring unity of effort between U.S. and other Arab coalition military forces. One of ARCENT's objectives during CPX Lucky Sentinel 00 was to exercise this staff organisation, referred to as the Friendly Force Co-ordination Centre (F2C2). The F2C2 operation was considered a success upon which to build in future exercises.

Reference Web Sites: http://www.globalsecurity.org/military/ops/lucky-sentinel.htm

E.5 ROVING SANDS

Roving Sands is the world's largest multinational joint theatre and air missile defence training event, employing high-tech weapons systems, aircraft and tactical vehicles. Soldiers, sailors, airmen and marines from the United States, as well as forces from Germany, the United Kingdom and the Netherlands participated in Roving Sands '99. The participation of about 2,000 German and Dutch air defenders marked the first large-scale deployment of German and Dutch ground forces in a multinational exercise on American soil. Roving Sands '99 took place in the Southwest Texas and Southern New Mexico area. Air and missile defence forces refined their joint and multinational interoperability skills using a joint integrated air defence network of ground, missile and radar early warning systems. They faced an

opposing force of tactical aircraft, ballistic and cruise missiles in a high-threat environment. Army, Marine and the Roving Sands '99 contingent of multinational air and missile defence forces employed Patriot, Hawk, Roland, Mark 1 Alpha Missile, Avenger and Stinger air defence systems against realistic front-line attack forces.

Web Sites:

General Info: https://do.acc.af.mil/dg/Roving_Sands/default.htm

Roving Sands 97 Info: http://www.defenselink.mil/news/Mar1997/m032597_m042-97.html

Roving Sands 99 Info: http://147.71.210.21/adamag/july99/rovingsa.htm

Roving Sands 00 Info: http://www.forscom.army.mil/Rsands/

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14. Abstract

Within NATO, some countries already have ATBM (Anti-Tactical Ballistic Missile) capabilities, others are in the process of acquiring these. One of the issues will be interoperability between all NATO TBM defence elements, especially the Command and Control elements; tactical and procedural co-ordination between combined and joint EAD forces; and deployment and contribution of future systems. NATO and the nations can do something to improve C2 and turn individual weapon systems (point solutions) into an integrated defense system. This is especially important for those nations who do not possess their own TBM assets and must rely on an umbrella from other nations whilst contributing to counterforce or other aspects of a mission. The only way of knowing of how Nations can achieve this is through modelling and simulation (and progressively work to a situation where the simulated elements are replaced by real ones). This simulation environment could also provide a training framework. The NATO RTO Modelling and Simulation Group (NMSG) recognized the role that interoperable simulations could play in the TBMD field and set up a Task Group to investigate this area. The report of the MSG006/TG006 exploratory group describes the issues relating to EAD and C2 interoperability within NATO, the current use of M&S to support the EAD field (e.g. training, research and analysis) and it identified opportunities for improved M&S support. The findings of the study include the fact that although the High Level Architecture (HLA) is the accepted standard for M&S interoperability, many existing models and simulations can not effectively interoperate due to lack of compliance either to HLA or to a standardised datamodel (e.g. covering tactical datalinks).

The TG proposes to set up a follow-on programme to demonstrate the possibilities of M&S through a Reference Testbed for NATO TMD. The activities of this follow-on Task Group will be harmonized with the NATO Active Layered Theatre Ballistic Missile Defence (TBMD) Feasibility Studies. Results from the Reference Testbed study could also be applied to future European BMD projects with an emphasis on its linkage with the US BMD.

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